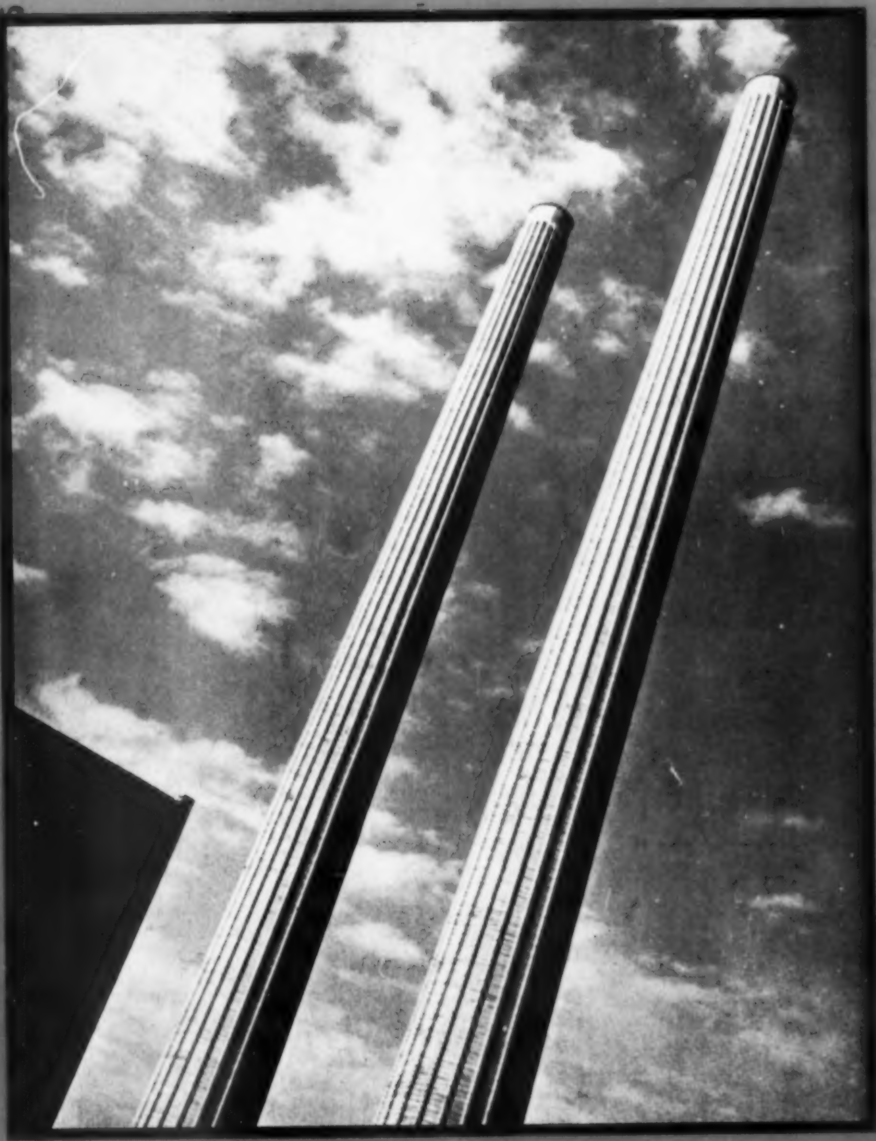
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

December 1952



Concrete Stacks at Dechy Station; see page 38

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Feature Articles

Editorials

Departments

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COMBUSTION

Editorials

Large Meeting Presents Problems

This year's Annual Meeting of the ASME was marked by both a record attendance and an extensive program that in many ways appeared to be above the average in the character of papers presented. The very large attendance, while symbolizing the growth of the Society, nevertheless created a problem in that it appeared to have outgrown the hotel accommodations—this despite the supposedly ample facilities of the Statler and the fact that some of the sessions and those of the affiliated American Rocket Society were this year held in a second hotel, the McAlpin. Some of the more popular sessions packed the larger halls at the Statler beyond both seating and standing capacity, and thus many of those interested were denied participation. Moreover, judging from the corridor comments of some out-of-town visitors, guest accommodations at the hotel were overtaxed to the point of creating dissatisfaction.

Obviously, such an extensive program involves numerous simultaneous sessions which make necessary a choice between not only technical subjects of primary concern, but also between such subjects and others of more general or economic interest.

The opinion is sometimes expressed that contacts with fellow engineers constitute the chief advantage of attendance at such annual meetings. But, without minimizing the value of such contacts, it would seem that the packed sessions attest to the importance placed on the papers and the discussions; especially since it is no longer expedient to make complete transactions of the meeting available to the entire membership within the scope of annual dues.

No criticism is due those responsible for running the meeting. They were wrestling with a difficult problem. New York City appears to be due for expanded hotel accommodations. A huge municipal auditorium, such as is now being tentatively planned, would be of no help for such a meeting, which requires a number of large rooms. For the present, perhaps the answer may lie in a smaller, more selective program.

Beyond the Call of Duty

Day-to-day functioning of a public utility system seldom makes newspaper headlines except in cases of major disruptions of service. But there are occasions when routine maintenance assumes a dramatic quality that reminds the general public of the devoted service of the men who man the machines. Such was the case on November 28 at the Astoria gas-coke plant of the Consolidated Edison Company of New York.

Two men, William Eckel and Edward Glennon, were engaged in pointing up loose bricks near the top of a 262-ft stack on a blustery day with winds up to 40 mph. A sudden downdraft of waste stack gases, largely carbon monoxide, enveloped the men, and Mr. Glennon became ill. Mr. Eckel managed to lash his co-worker to the stack and then descended the iron ladder to summon help. At this point Patrick McPartlan, a 33-year old rigger employed by Consolidated Edison, volunteered to attempt the rescue of Mr. Glennon, an employee of the Preuss Construction Company. Mr. McPartlan climbed the ladder, hand-over-hand, to the equivalent of twenty-five stories, found Mr. Glennon unconscious, but managed to extricate him from the ladder and adjust his safety belt so that the mason could be lowered slowly by a block and tackle controlled by other rescuers on the ground. To insure that Mr. Glennon would not be crushed against the ladder by the high wind, Mr. McPartlan held the unconscious man away from the stack throughout the descending process. Both men were given oxygen and Mr. Glennon soon revived.

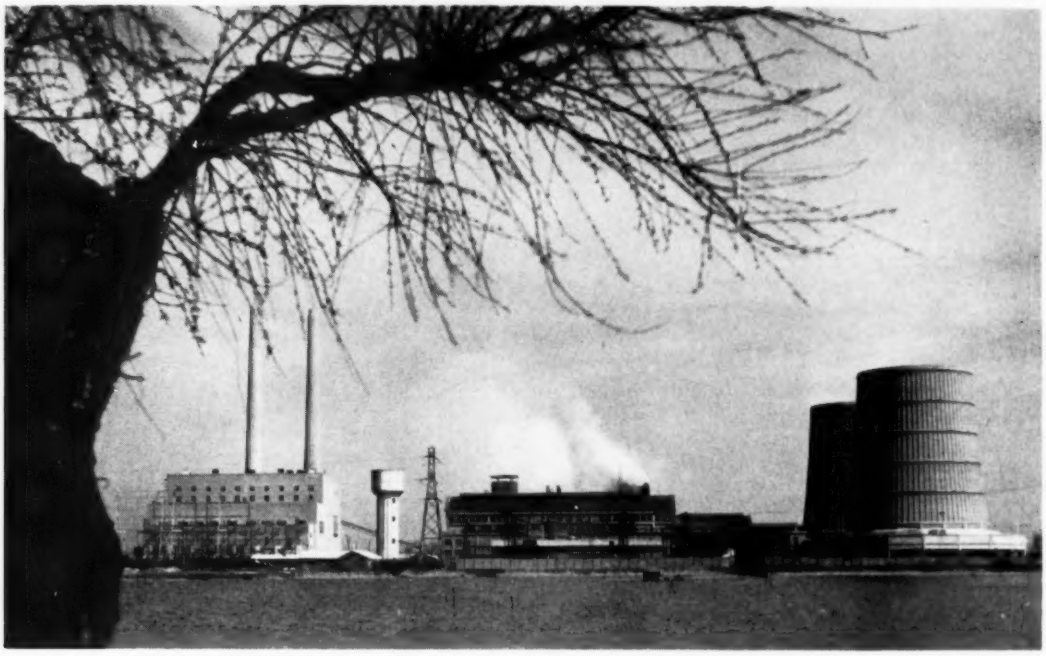
This type of devotion beyond the call of duty is not unfamiliar nor uncommon in the public utility industry. Almost every operating company has records—and warm memories—of the heroic efforts of men whose sense of human welfare caused them to rise unhesitatingly to meet an emergency. As in the episode just narrated, the call to duty arises spontaneously and encompasses a service motive. And it serves to remind us that in the routine business of producing kilowatts, gallons of water or cubic feet of gas it is the human being who is capable of responding beyond the call of duty.

Dr. Harvey N. Davis

As we are about to go to press comes an announcement of the death of Dr. Harvey N. Davis, president emeritus of Stevens Institute of Technology and past president of the American Society of Mechanical Engineers.

Dr. Davis was widely known as an educator, engineer and scientist. As an authority on thermodynamics, he was perhaps best known to engineers in the power field for his research on the properties of steam while a professor at Harvard, which led to his co-authorship of the early Marks and Davis Steam Tables. He was also the author of numerous scientific papers in the fields of steam and air liquefaction and, from time to time, had served as consultant to several large engineering companies. In World War I he did research work on helium for the armed forces and was also identified with the Office of Production Research and Development. His contribution to the second World War was in the field of accelerated engineering training of Navy personnel.

As an ardent advocate of basic unspecialized training in engineering curricula, such as would qualify the student for subsequent administrative responsibilities, Dr. Davis left his imprint not only on the institution which he long served, but exercised an outstanding influence in educational circles.



Dechy Station with cooling towers at right, old plant in center

DECHY POWER PLANT

at Sin-Le-Noble, Nord France

By S.C. WEINER and E. ASLAKSEN

Gibbs & Hill, Inc., New York

This is another Marshall Plan station of 120,000-kw initial capacity in two units built primarily to serve a mine load with excess power feeding a transmission network. Because of the low-cost refuse fuel, running up to 35 per cent ash, 10 per cent volatile, and with a heat value of 8700 Btu per lb, the furnace was designed for low heat release, and conservative steam conditions of 885 psig, 900 F were adopted. This fuel is fired by vertical burners supplied by bowl mills with oil or gas burners employed to stabilize the coal flame at very light loads. The station heat rate is 11,950 Btu per net kwhr.

The new 120,000-kw Dechy Power Plant of the Houilleres du Bassin du Nord et du Pas-de-Calais is located in the midst of a narrow coal belt about 10 miles wide and extending some seventy-five miles in the east-west direction across the northern part of France. It is about 18 miles south of Lille and about 2 miles from Douai. Constructed by the Mines under the Marshall Plan with Gibbs & Hill, Inc., New York, as consulting engineers, the modern Dechy plant has received widespread notice in Europe. It is one of thirteen plants of the nationalized mines, all of which burn refuse coals of high ash content and low heating value. The generated power in excess of mine requirements is transferred to networks feeding Paris and other areas.

The successful operation since 1949 of Harnes,[1] the sister plant located some twelve miles to the west, prompted duplication of equipment wherever possible. The carryover of operating and maintenance experience with duplicate equipment and the savings in spare parts inventory is the resultant dividend.

Where differences between Harnes and Dechy exist, each variation has its background. Harnes was built with a steam header system because boiler availability with the poor grade of coal to be used was an unknown quantity. The steam-generating equipment proved to have such high availability that a unit system of one boiler per turbine instead of two was selected for Dechy. In the interest of minimizing structure and because more ground was available at Dechy, the fans, dust collectors and concrete stacks were put at low level.

Although Combustion Engineering furnished the boilers for both plants, the tangential burner design for Harnes gave way to the vertical burners for Dechy because of the extremely low volatile content of the coal (10 per cent). Fluctuating fuel composition with its attendant burden on operation was avoided at Dechy by the installation of a coal-preparation and blending

[1] See COMBUSTION, August 1949.

plant. To save power and also in their concerted effort to furnish French material and equipment wherever available, the Mines provided natural-draft cooling towers instead of the induced-draft type as employed at Harnes.

With electrostatic precipitators at a low level, it was possible to remove dust from the hoppers through dustless unloaders directly onto belts and thence into railroad hopper cars.

The two Westinghouse 3000-rpm turbine-generators are of the tandem-compound, double-flow, impulse-reaction type, nominally rated at 60,000 kw with 16,200-volt, 3-phase, 50-cycle generators 0.8 pf at 25 psig hydrogen pressure. The direct-driven main exciter and pilot exciter are 220 kw, 250 volts and 2.5 kw, 250 volts, respectively.

Because of the low-cost refuse fuel, the conservative throttle steam conditions of 850 psig 900 F adopted for Harnes were repeated. Steam is extracted at five points for feedwater heating in the regenerative cycle; namely, the 5th, 11th, 17th and 23rd stages of the high-pressure cylinder and the 4th stage of the low-pressure cylinder. Panel-mounted instruments are provided to record turbine steam and metal temperatures furnishing the operator with the necessary information for rapid starting in the future.

Plant Heat Balance

The heat balance for one unit is shown below. The first or highest pressure extraction stage is equipped with a horizontal heater. The next lower extraction stage is equipped with a horizontal heater and integral drain cooler. The evaporator heating steam is also bled from this stage. The third highest extraction steam is used for heating the deaerator. Evaporator vapor is discharged to the deaerator as makeup to the cycle.

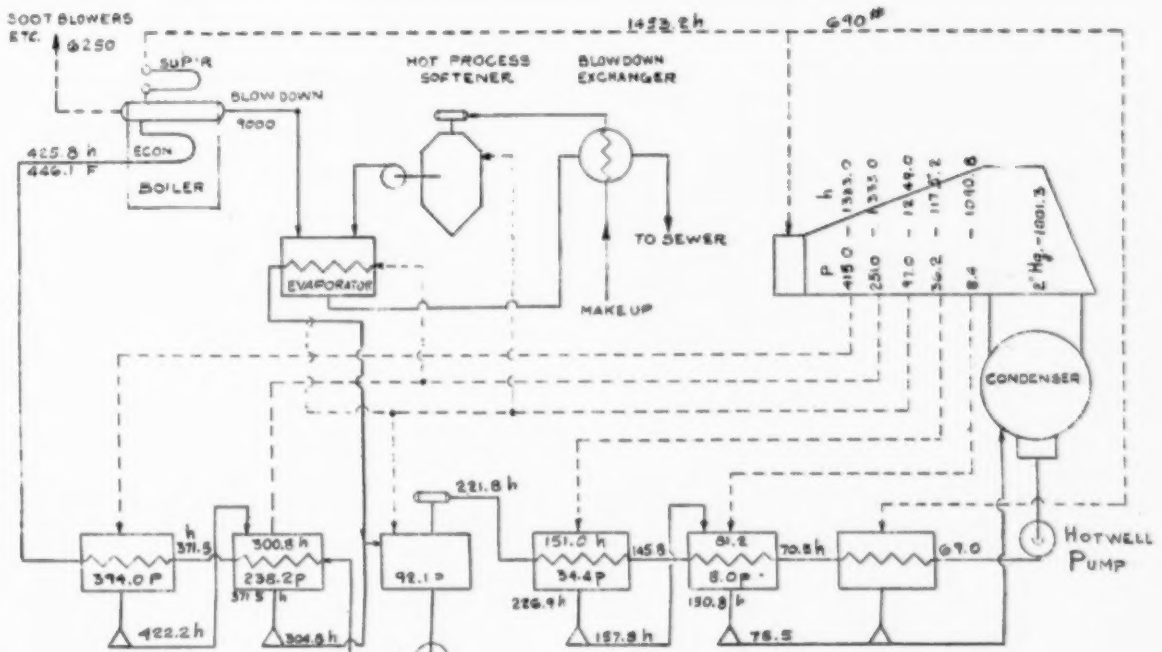
Of the two low-pressure heaters below the deaerator physically and in pressure, the highest has an integral drain cooler and the lowest a separate one. The lowest extraction heater is mounted in the neck of the condenser to conserve extraction piping. The drains from all heaters and drain coolers cascade to the next lower heater at all loads. No drip pumps are employed.

At 62,500-kw output and 2-in. Hg back pressure, the turbine heat rate is calculated at 9523 Btu per kwhr and the station heat rate under the same conditions at 11,950 Btu per net kwhr. The reduction from the 12,050 Btu per net kwhr calculated for Harnes is principally due to absence of cooling tower fan power at Dechy where the natural-draft type is used.

The zero-oxygen deaerators are of the tray type with conventional storage and have a baffled suction to avoid vaporizing in the feed pumps upon sudden decreases in load. In addition to generous net positive suction head provided for the boiler feed pumps, a steam pressure reducing valve fed from the drum is arranged to cut in and keep the deaerator pressure from falling below atmospheric on loss of load.

Each unit system has an evaporator fed by a common hot-process softener. Space was left for a third unit, although this provision has proved to be unnecessary.

The condensate control system is simple and has proven satisfactory. It consists of a deaerator-condensate inlet valve actuated from hotwell level and hotwell



Heat-flow diagram

makeup and condensate discharge to storage valves actuated from deaerator level.

The Ingersoll-Rand condensers have 45,000 sq ft of $^{7}/_{8}$-in. tubes, 24 ft long and are of the two-pass type with divided water boxes. Circulating water to each condenser is supplied by two vertical pumps of the axial-flow type delivering a total of 45,000 gpm from a separate building located between the two atmospheric natural draft towers. These towers are designed to cool a total of 90,000 gpm through an 18 deg range, at 68 F ambient and 85 per cent relative humidity. Each tower takes care of one condenser using 54-in. piping which divides into 36-in. branches both at the condenser and at the cooling tower.

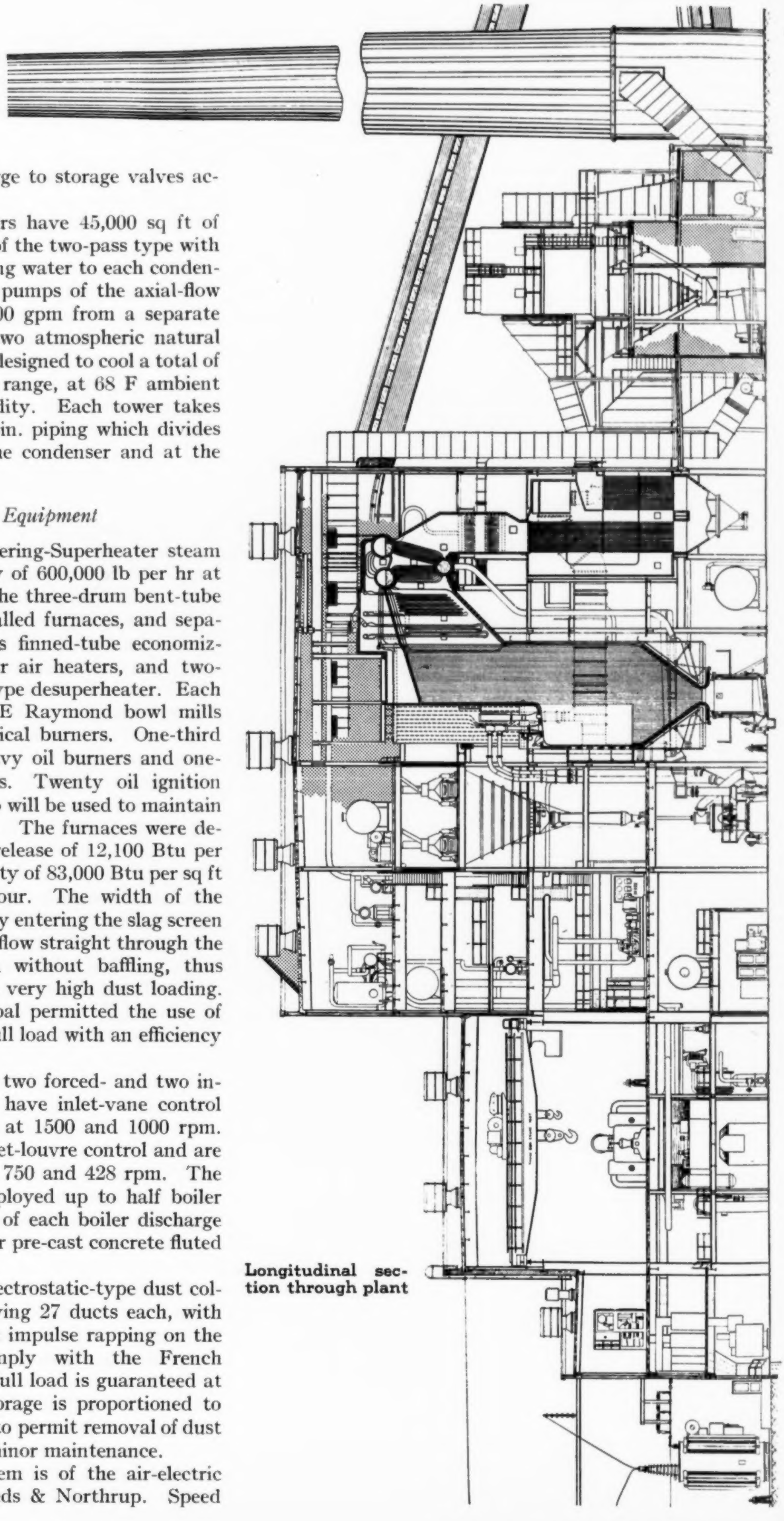
Steam Generating Equipment

The two Combustion Engineering-Superheater steam generators each have a capacity of 600,000 lb per hr at 885 psig, 900 F. They are of the three-drum bent-tube type with dry-bottom water-walled furnaces, and separately set split-type continuous finned-tube economizers, vertical two-section tubular air heaters, and two-stage superheaters with spray-type desuperheater. Each unit is direct fired by five C-E Raymond bowl mills supplying twenty Lopulco vertical burners. One-third load can be carried by ten heavy oil burners and one-sixth load by ten gas burners. Twenty oil ignition torches are furnished, which also will be used to maintain stable coal flame at light loads. The furnaces were designed for a conservative heat release of 12,100 Btu per cu ft per hr and a heat availability of 83,000 Btu per sq ft of black projected area per hour. The width of the boiler results in a low gas velocity entering the slag screen of 14 ft per second. The gases flow straight through the superheater and boiler section without baffling, thus avoiding tube erosion from the very high dust loading. The low sulfur content of the coal permitted the use of 283 F exit gas temperature at full load with an efficiency of 86.3 per cent.

Each boiler is equipped with two forced- and two induced-draft fans. The former have inlet-vane control and are driven by two motors at 1500 and 1000 rpm. The induced-draft fans have inlet-louvre control and are driven by two-speed motors at 750 and 428 rpm. The low speeds of the fans are employed up to half boiler loads. The induced-draft fans of each boiler discharge the gases to a 11 ft 6 in. diameter pre-cast concrete fluted stack 360 ft high.

The Research Corporation electrostatic-type dust collector consists of two units having 27 ducts each, with continuously-operated magnetic impulse rapping on the collecting electrodes. To comply with the French Morizet Law, the efficiency at full load is guaranteed at 96.2 per cent. The hopper storage is proportioned to give 12-hr capacity at full load to permit removal of dust twice daily and allow time for minor maintenance.

The combustion-control system is of the air-electric metered type furnished by Leeds & Northrup. Speed



Longitudinal section through plant

of the coal feeders and the position of the induced-draft inlet louvres are regulated from the pressure-governed master control with steam-flow air-flow proportioning. Furnace suction is automatically maintained by regulation of the forced-draft inlet vanes. With the proportioning air-flow controller, up to 50 per cent of oil or gas, or oil and gas, may be used in combination with the coal on automatic control. The number of mills in operation and the speed of the fans are at the discretion of the operator, who is warned in the control room by alarms when such equipment is limited. Interlocks are provided to open and close vanes and louvres when fans are put in or removed from service.

Each boiler is served by three boiler feed pumps, two motor-driven and, for standby, one steam-driven pump. Each is of sufficient capacity to carry about 55 per cent of full boiler load. The pumps are of the opposed-impeller volute type and are driven at 3600 rpm by the motors, through step-up gears and directly by the steam turbine.

Another view of Dechy

Coal and Ash Handling

All coal-handling equipment external to the plant is of French manufacture and design and includes two car dumpers, track hoppers, tractors, conveyors and a complete blending plant, where the coal from various mines is mixed to feed the plant with a uniform mixture. Twin inclined conveyors of 220 short tons capacity each feed two similar capacity bunker conveyors. Each pulverizer has an overhead bunker with 10-hr storage.

The bottom ash and air-heater hopper ash are handled hydraulically to a common plant sump, from which they are pumped to dewatering tanks located beyond the stacks in a central ash-handling area.

The fly ash from each boiler is discharged from each of four breechings, first- and second-section precipitator hoppers to an aerated hopper and then to a dustless unloader. The four dustless unloaders of each boiler discharge to a belt conveyor system which, in turn, empties into a chute hopper over tracks in the central ash-handling area. The system was made as simple and direct as possible to minimize maintenance. Six hundred tons of ash must be handled daily under the anticipated plant load schedule.

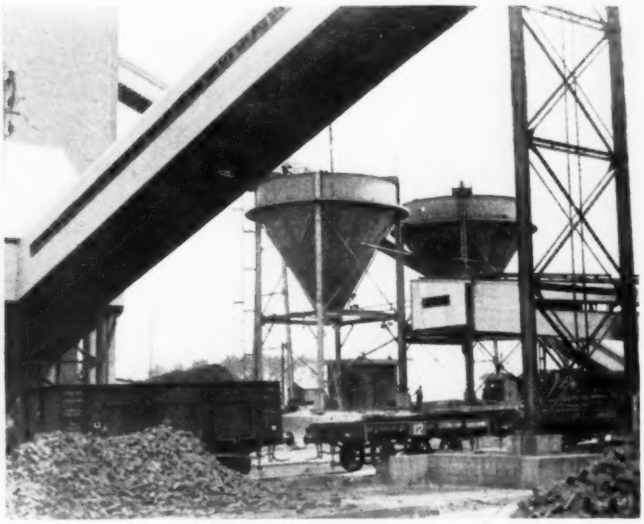
Water Treatment

Both cooling tower and evaporator makeup from wells are treated in a French-designed and fabricated plant located between the pump house and the main building and then stored in an elevated concrete tank. Treated water for the cooling tower is fed to the basins and supplemented with acid under pH control, while the water for the evaporators is further softened by a sludge blanket type of hot-process softener.

The boilers are treated internally with trisodium phosphate, and the evaporators with monosodium phosphate. Sodium sulfite and caustic are introduced into the high-pressure feedwater at a point following the takeoff for condensate for the spray desuperheaters.

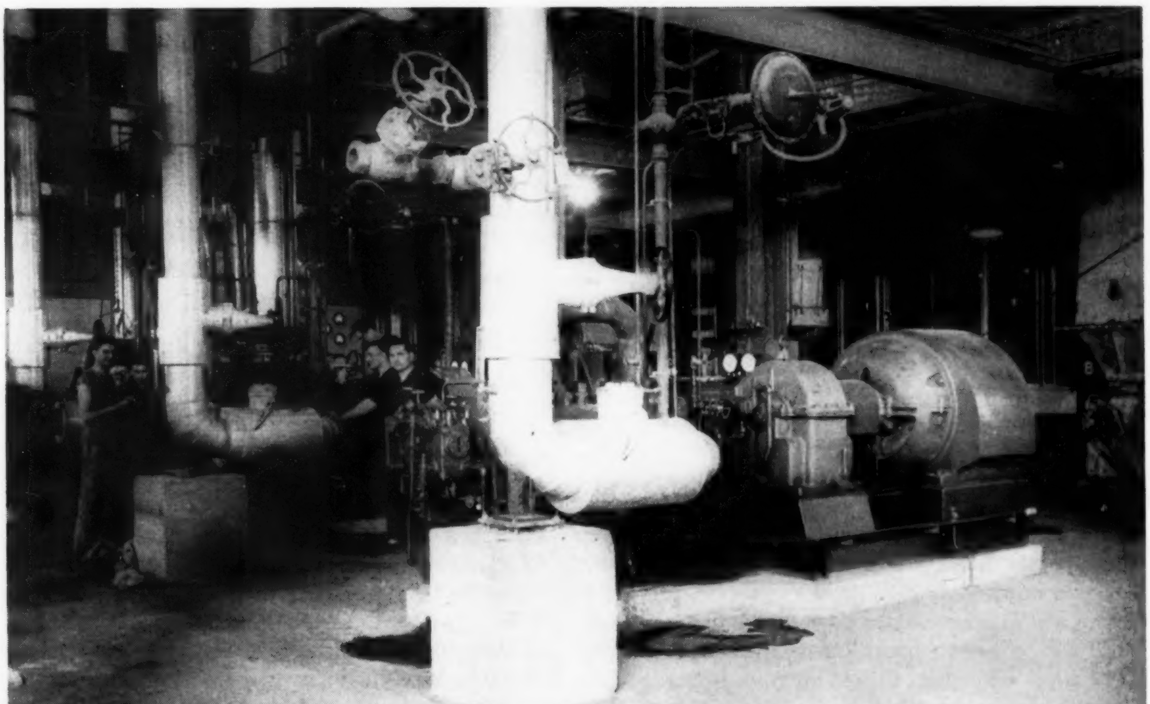
Electrical System

The combined maximum output of the two generators is 120,000 kw or 150,000 kva at 0.8 pf with 25-lb hydrogen cooling pressure. Subtracting about 10,000 kva for auxiliary power requirements leaves 140,000 kva available for outgoing power. A varying portion of this power, up to 85,000 kva maximum will be supplied at generator voltage over four 30,000-kva feeders, normally three in service and one spare, to the old plant to sup-



Coal- and ash-handling system

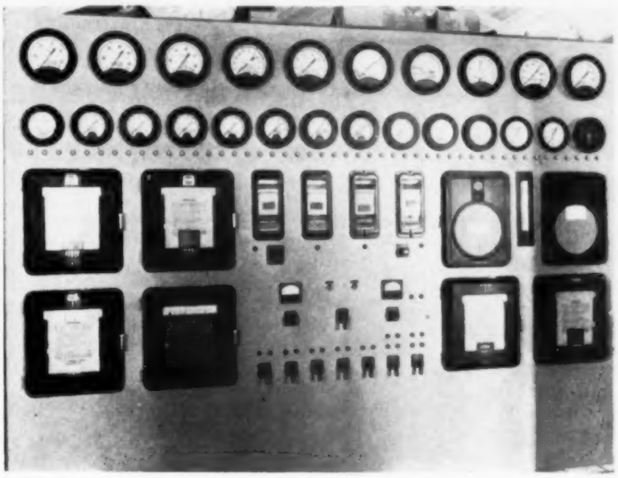
Construction view of furnace



General view of the pump room

plement its existing generating capacity for power to the local mining area over some 30–15.75-kv radial feeders, and through step-up transformers to the 45-kv and 150-kv systems. The remainder of the total output is supplied to the 220-kv power system of the nationwide Electricite De France (E.D.F.) through two banks of step-up transformers and over two outgoing lines.

The 16.2-kv bus consists of cubicle type completely-enclosed switchgear with 5000-amp, air-operated, air-blast circuit-breakers with 2500 mva interrupting rating. To provide for flexibility of operation and fill the requirements with a minimum of circuit-breakers, the arrangement as shown in the diagram on page 44 was selected. This arrangement provides for dual methods of operation for each generator as follows:



Turbine control board

1. As a unit supplying all the output through the step-up transformer bank to the 220-kv system.
2. Supplying power at generator voltage to the old plant only, or in addition to the power furnished to the 220-kv system.

In order to obtain neutral grounding facilities for both methods of operation, the generators are provided with neutral grounding transformers for unit operation and a 30-ohm grounding resistor is connected through circuit-breakers to either of the two general auxiliary power transformers as shown on the diagram.

The circuit-breakers in the old plant set a limit of 1000 mva short-circuit level on the old plant bus, so that 0.75 ohm reactors were required for each of the four feeders from the new plant. The generator voltage at the new plant is therefore varied at the new plant to compensate for the drop in the reactors and maintain a constant 15.75-kv potential on the old station bus. For that reason, as well as to provide for voltage and reactive component regulation on the 220-kv system, the main step-up transformers are provided with wide range, ± 18 per cent in 33 positions, tap-changers under load on the 16.2-kv winding. These tap-changers are motor operated, remote controlled from the main control board. The two transformer banks consist of three 20,000/25,000 fan-cooled single-phase units each. A seventh spare transformer is permanently installed between the two banks and arranged so that it may replace any one of the other six without being moved.

The five 230-kv oil circuit-breakers are pneumatically operated and have an interrupting rating of 5000 mva. Calculations showed that rating to be the minimum permissible for this installation which gives an indication of the magnitude of the power system.

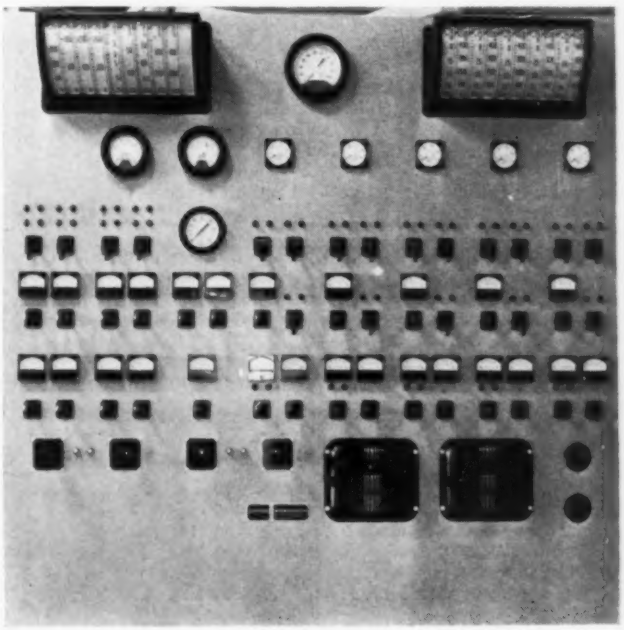
The outgoing 15.75-kv feeders to the local mine area consist of underground cables, and the comparatively high resistance (30 ohms) provided for the 16.2-kv neutral grounding limits a ground fault current to about 315 amp, to prevent excessive damage to the lead-covered cables. As a result it was necessary to provide low-energy, directional, ground-fault relays for all 16.2-kv equipment in addition to the usual differential and over-current relays.

A 3.2-kv, 3-phase switchgear with drawout-type air circuit-breakers is provided for all auxiliary motors above 100 hp. This switchgear is divided into three sections, one for each unit and a general service and starting section. The motors are of the full-voltage starting induction type.

The 400-volt auxiliary power system is arranged in the same manner as the 3.2-kv system for motors of less than 100 hp. In addition, 400-volt power centers are provided for the coal- and ash-handling equipment, and for the pump house located between the natural-draft cooling towers.

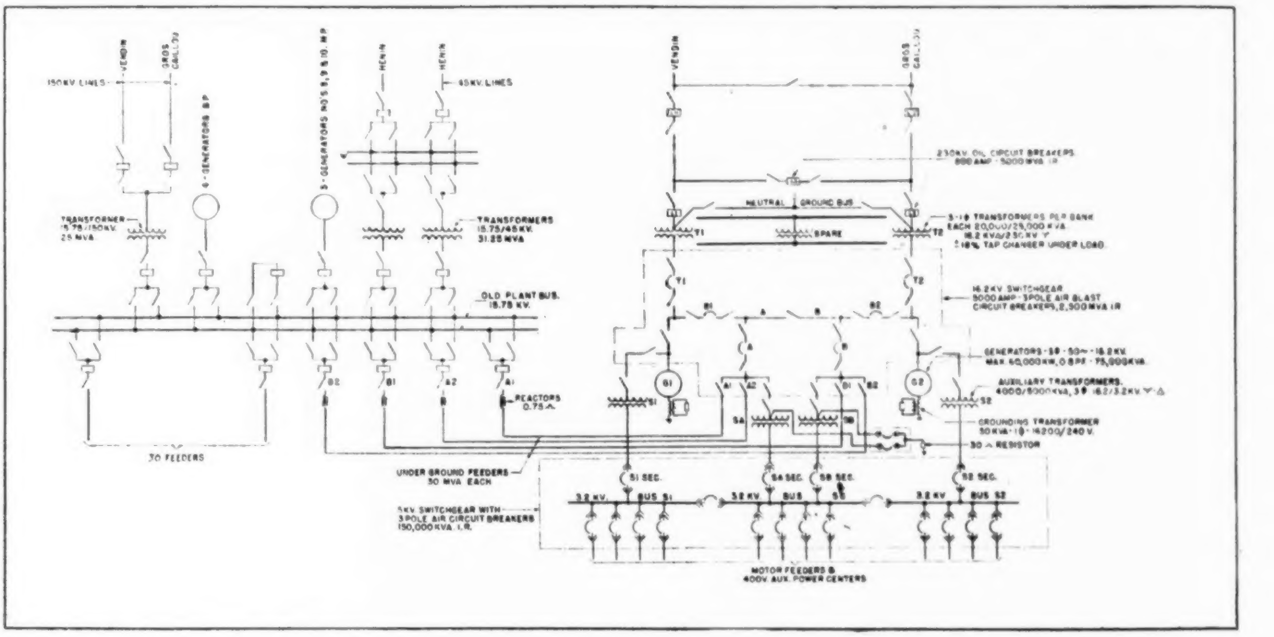
The complete auxiliary power system is arranged so as to provide flexibility in operation and maintenance as well as continuity of service.

A central control room is located on the operating floor between the turbine room and the boiler room, the combined controls for boilers, turbines and electrical equipment being located in this room.



Boiler control board

The erection of the plant was performed in record time, due to a close coordination between the Mine officials, their engineers, French contractors and the American engineering representatives. The start-up of the first unit went off smoothly in time for the official inauguration on June 22, 1952, which also celebrated the 100th anniversary of the Mines. The second unit is now in service, and the station is in full operation.



General layout of electrical system

AMERICAN EQUIPMENT OF DECHY POWER PLANT

Air conditioner	Trane Co.
Ash-handling equipment	Allen-Sherman-Hoff Co.
Flyash-handling equipment	United Conveyor Corp.
Blowdown heat-exchangers	Ross Engineering Co.
Boilers	Combustion Engineering-Sup'h't'r.
Coal-handling equipment	Link Belt Co.
Combustion control and instruments	Leeds & Northrup
Flowmeters	Bailey Meter Co.
Air compressors	Ingersoll-Rand Co.
Condensers and auxiliaries	Ingersoll-Rand Co.
Turbine-room crane	Manning, Maxwell & Moore
Ducts and dampers	Connery Construction Co.
Dust collectors	Research Corp.
Evaporators	Griscom-Russell Co.
Mechanical draft fans	Westinghouse-Sturtevant
Pressure gages	Crosby Steam Gage & Valve Co.
Deaerating heaters	Elliott Co.
Condenser neck heater	American Locomotive Co.
Feedwater heaters & drain coolers	Griscom-Russell Co.
Oil conditioning	S. F. Bowser & Co.
Piping	M. W. Kellogg Co.
Coal piping	Stock Engineering Co.
Boiler-feed pumps	Worthington Pump & Machy. Corp.
Chemical-feed pumps	Milton Roy Co.
Circulating-water pumps	Ingersoll-Rand Co.
Hotwell pumps	Ingersoll-Rand Co.
Miscellaneous pumps	Turbine Equipment Co. (Peerless & DeLaval)
Turbine-generators	Westinghouse Electric Corp.
Fuel oil pump & heater set	Peabody Engineering Co.
Hot-process softener	Permutit Co.
Three-element f.w. control	Bailey Meter Co.
Boiler-feed recir. control	Bailey Meter Co.
Reverse flow valves	Atwood Morrill
Thermometers	Weksler Thermometer Corp.
Steel globe-valves	Edward Valves, Inc.
Steel gates-valves	Crane Co.
Iron and bronze valves	Crane Co.
Small forged valves	Manning, Maxwell & Moore
Special valves	Malcolm W. Black (Fisher Gov.)
16.2 KV Switchgear	General Electric Co.
380-v. motor starters	General Electric Co.
3.2-kv starters	Westinghouse Electric Corp.
400 v starters	Westinghouse Electric Corp.
Main power transformers	Allis-Chalmers Mfg. Co.
Auxiliary power transformers	Westinghouse Electric Corp.
230 KV circuit-breakers	Westinghouse Electric Corp.
Duplex control & relay board	Westinghouse Electric Corp.
230 KV disconnecting switches	Delta Star Electric Co.
Generator segregated bus structure	Delta Star Electric Co.

Fuels in a Technical Economy*

A study of the fuel consumption in the United States for industrial purposes—as distinguished from domestic, power generations and transportation uses—discloses the following interesting facts:

In 1938 industry consumed 158 million net tons of bituminous coal, including coke-oven requirements, and in 1950 this increased to 224 million net tons, or by 41 per cent. Again in 1938 electric power sales for industrial and commercial purposes were 62,270 million kilowatt-hours, and in 1950 they were 189,500 million kilowatt-hours, or 205 per cent more.

Industrial oil consumption increased from 60 million barrels in 1938 to 185 million barrels in 1950, or by 208 per cent, and industrial gas sales increased from 7,941 million therms in 1938 to 22,886 million therms in 1950, or 187 per cent.

In the same period our national gross product value or national expenditure increased from approximately 90 billion in 1938 to 282 billion in 1950, or 201 per cent. If we apply a correction for the depreciation of our money value to this dollar evaluation, say a sixty-six cent dollar in 1950 against 1938, our gross national product value increased only 132 per cent in this same twelve-year period. Since the fuel figures are expressed in units of measurement rather than dollar value, it is obvious that our refined fuels have a higher percentage of increase than our total national production. This permits the conclusion that the industrial consumption of fuel plays a proportionately higher role of importance in our productive plant.

* Excerpts from an address by Frederic O. Hess, president of the Selas Corporation of America at the Fuels Division Luncheon during the ASME Annual Meeting

STEAM AND ELECTRIC POWER—
Its Past and Future

In this paper, given at the Century of Engineering in September at Chicago, from which the following is briefed, the author traces the progress of stationary steam power over the last fifty years, particularly as reflected in the economy of generation and use of fuel. Looking to the future he estimates that by 1970 the annual utility output will be around 1000 billion kilowatt-hours, with a corresponding installed capacity of 200 million kilowatts. Of this total output 75 per cent will be generated by fuel, of which coal will account for 80 per cent. He anticipates further that by 1970 the average annual station heat rate will have been reduced to 10,000 Btu per kwhr.

By THEODORE BAUMEISTER

Stevens Professor of Mechanical Engineering, Columbia University

STEAM power is the backbone of present-day stationary practice. Hydro power finds applicability here but its relative magnitude is not great as is evidenced by the data of Tables 1 and 2 on capacity and energy for electric utilities. These tables also serve to demonstrate the minor role played by internal-combustion engines in the generation of electric energy. This is in direct contrast to the predominant position of internal combustion in the field of transportation where it dwarfs all other sources.

This paper is concerned with the application of steam power to the generation of electric energy. As such it is limited to stationary practice.

A similar picture can be developed for those stationary power plants which are designed specifically to serve an associated manufacturing enterprise. In the process industries and in building heating installations there are demands for heat, as well as for electric power. The thermostatic exactness of the vapor-tension relation, the high latent heat, the reasonable density and pressure, and the universality of the fluid make steam the predominant medium for delivering the required heat to process. Where there is a combined demand for electric power and process heat, the steam system offers the potentiality of the dual purpose, or "by-product" power plant.

The boiler pressure can often be selected so as to produce much, if not all, of the electric power as a by-product of the process or building heating requirements. Hydro, internal-combustion engines and gas turbines are all at a distinct disadvantage when considered for this multiple-purpose power service. Steam dominates this field of multi-purpose industrial power even to a greater extent than in the case of the electric utility. The problem with the electric utility is greatly simplified because there is just one objective—to deliver a single product, the kilowatt-hour.

Steam plants have a further important merit because they can utilize practically any source of heat and convert that heat economically to the useful form of electrical energy or process steam. This means that the steam plant can use any fuel that will burn—coal, oil, gas, or waste—as a source of raw energy. It can also collect, conserve, and convert the waste heat of industrial operations for useful purposes. Steam power has thus stood the test of long experience and its dominance in the stationary power field cannot be gainsaid.

The paramount position of steam power in the stationary field rests upon its economy and its reliability. Both factors have shown remarkable development over the years. Perhaps the most significant contribution to economy stems from the cost of fuel needed to operate the plant and to deliver a kilowatt-hour or a pound of steam. The engineering profession has made repeated contributions in this respect as is evidenced by the data of Tables 3 and 4. These tables give some representative

TABLE NO. 1

INSTALLED CAPACITY OF ELECTRIC UTILITY GENERATING PLANTS

UNITED STATES 1920 - 1951

Adapted from Federal Power Commission Data

		Million Kilowatts			Percentage		
Year	Total	Hydro	Steam	Int. Comb.	Hydro	Steam	Int. Comb.
1951	75.5	18.8	— 56.7 —		24.9	— 75.1 —	
1950	68.9	17.7	49.3	1.9	25.7	71.6	2.7
1949	63.1	16.7	44.6	1.8	26.5	70.7	2.8
1948	56.6	15.7	39.3	1.6	27.7	69.5	2.8
1947	52.3	15.0	36.0	1.3	28.7	68.8	2.5
1946	50.3	14.8	34.3	1.2	29.4	68.2	2.4
1945	50.1	14.9	34.1	1.1	29.7	68.1	2.2
1944	49.2	14.6	33.5	1.1	29.7	68.1	2.2
1943	48.0	13.9	33.0	1.1	29.0	68.7	2.3
1942	45.0	12.8	31.2	1.0	28.5	69.2	2.3
1941	42.4	11.8	29.6	1.0	27.8	69.9	2.3
1940	39.9	11.2	27.8	0.9	28.1	69.6	2.3
1935	34.4	9.4	24.4	0.6	27.3	71.1	1.6
1930	32.4	8.6	23.4	0.4	26.5	72.2	1.3
1925	21.5	5.9	15.4	0.2	27.6	71.6	0.8
1920	12.7	3.7	8.9	0.1	29.1	70.2	0.7

and unique values of thermal economy as experienced in utility and industrial steam power plants. They show not only the historical story but they also indicate future potentialities. Thus, the early installations of James Watt, if applied to electric practice, could deliver one kilowatt-hour equivalent to 3413 Btu of energy for the expenditure of 150,000 to 200,000 Btu per hr in fuel.

TABLE NO. 2

ELECTRIC UTILITY GENERATION BY SOURCES OF ENERGY

UNITED STATES 1920 - 1951

Adapted from Federal Power Commission Data

	Billion Kilowatt Hours per Year				Percentage		
Year	Total	Hydro	Steam	Ice	Hydro	Steam	Ice
1951	370.2	99.8	— 270.4 —		26.9	— 73.1 —	
1950	329.0	95.9	229.5	3.6	29.0	69.9	1.1
1949	291.1	89.7	197.9	3.5	30.7	68.1	1.2
1948	282.7	82.5	196.9	3.3	29.2	69.6	1.2
1947	255.7	78.4	174.5	2.8	30.7	68.2	1.1
1946	223.2	78.4	142.4	2.4	35.1	63.8	1.1
1945	222.5	80.0	140.4	2.1	35.9	63.2	0.9
1944	228.2	74.0	152.3	1.9	32.4	66.8	0.8
1943	217.7	73.6	142.4	1.7	33.8	65.4	0.8
1942	186.0	63.9	120.5	1.6	34.4	64.7	0.9
1941	164.8	50.9	112.3	1.6	30.9	68.1	1.0
1940	141.8	47.3	93.0	1.5	33.3	65.6	1.1
1935	95.3	38.4	56.1	0.8	40.3	58.9	0.8
1930	91.1	31.2	59.3	0.6	34.2	65.1	0.7
1925	61.5	21.8	39.4	0.3	35.5	64.0	0.5
1920	39.4	15.8	23.4	0.2	40.0	59.6	0.4

This is equivalent to a conversion efficiency of the order of two per cent. By the start of the twentieth century the great reciprocating engines could deliver a kilowatt-hour for 40,000 to 50,000 Btu, which is a reduction of nearly three-quarters in the fuel requirement of the Watt plant.

The final step in reciprocating steam practice was represented by the 7,500 kw duplex, angle-compound, engine-generator sets installed in the Interborough Rapid Transit plants of New York City. These engines delivered electric energy for an overall heat rate of 40,000 Btu per kwhr. They were rendered obsolete, practically overnight, by the development of the steam turbine. This development culminates today in turbine-generator units delivering more than 200,000 kw in a single boiler-turbine combination and doing it for an expenditure of 9000 Btu in fuel for each kilowatt-hour.

The end is not in sight even though this thermal performance gives a kilowatt-hour for about five per cent of the fuel used in the early plants of James Watt. This reduction of 95 per cent in fuel consumption over the years is impressive and it is only reasonable to ask how much further can technology carry us? The absolute limit, of course, is the mechanical equivalent of heat, or 3413 Btu per kwhr. But anyone with an understanding of thermodynamics will recognize that this would call for an impossible set of conditions either infinite source temperature or zero absolute atmospheric temperature. On the basis of present-day furnace temperatures of the order of 2500 F and atmospheric conditions of 40 F the practical limit of a perfect thermal power plant is set by the Carnot cycle at 4100 Btu per kwhr. This is the goal toward which fuel-burning plants can approach.

The improvement which has marked the progress of steam-electric power generation during the first half of the twentieth century is amply demonstrated by the thermal performance of all the electric utilities in their average heat rate, year by year. Fig. 1, based on Federal Power Commission figures, shows such data for the American public utilities in their steam power plants. The average heat rate has dropped from a value of 92,000 Btu per kwhr at the turn of the century to a value of 15,200 Btu per kwhr in 1951. This is a reduction of 76,800 Btu or 83 per cent in 51 years. This reduction in the fuel requirement is a compliment to the engineering profession. It has been achieved by the painstaking perfection of fuel-saving devices and methods. These include, most importantly, the steam turbine, high pressure, high temperature, high vacuum, high boiler and combustion efficiency, regeneration and resuperheat. In fact, the progress in heat rate over the first half of the present century has largely served to offset the advancing price of fuel during the same period. Fig. 2 and Table 5 show the value of production (coal prices) at the mines for the period of 1900 to 1950. When these prices are combined with the heat rates shown the results expressed as fuel cost in mills per kilowatt-hour, are as given in Fig. 3. Two curves are plotted in this figure. Curve *B* shows the fuel cost in mills per kilowatt-hour which would have prevailed if the heat rate had remained at its 1900 value of 92,000 Btu per kwhr but the fuel price had changed from year to year as shown in Fig. 2. This curve means that if there had been no progress in power generation efficiency over the years the fuel cost would have advanced from 3.7 mills per kwhr in 1900 to 17.2 mills per kwhr in 1950 or a rise of 360 per cent. There

TABLE NO. 3

THERMAL PERFORMANCE OF STEAM POWER PLANTS

OF HISTORICAL INTEREST

Expressed as net plant heat rate on the equivalent basis of Btu per kwhr.

Plant	Year	Unit Size Kw	Equivalent Heat Rate Btu per Kwhr
Savory steam engine plant	1600	—	2,000,000
Newcomen steam engine plant	1760	—	500,000 to 600,000
Watt steam engine plant	1780	—	150,000 to 200,000
Edison Pearl Street plant	1882	55	150,000
First steam turbine plant	1900	1500	50,000
74 Street, IRT, engine plant	1903	7500	40,000
Good steam turbine plant, World War I	1918	30,000	20,000
Good steam turbine plant, Post World War I	1925	40,000	15,000
Good steam turbine plant, World War II	1945	100,000	11,000
Best steam turbine plant, Post World War II	1952	200,000	9,000
Theoretical limit set by the Carnot Cycle with 2500 F combustion temperature	(Then) (Now) (Future)	—	4,100
Theoretical limit set by the Carnot Cycle with nuclear fission temperature of 10^6F	(Then) (Now) (Future)	—	3,413 -

was present, however, the offsetting influence of the advancing efficiency reflected in Fig. 1.

Thus curve *A* of Fig. 3 shows that in reality the cost for fuel, expressed as mills per kwhr, instead of rising, actually dropped from 3.7 mills in 1900 to 2.9 mills in 1950. The power engineer can lay claim to most of the credit

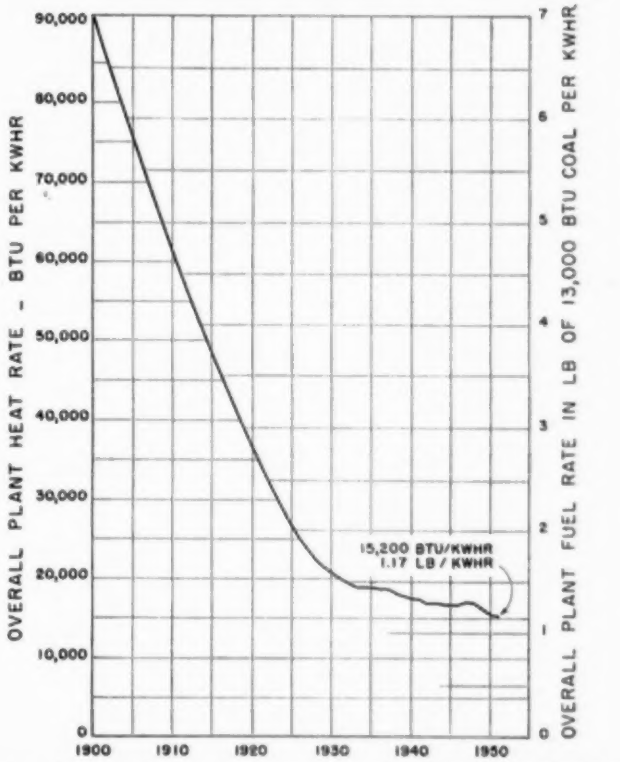


Fig. 1—Overall thermal performance of fuel-burning electric utility power plants in the United States, 1900–1951

(Adapted from Federal Power Commission Data)

for this remarkable state of fact. It is his contribution to the art of converting the raw energy of fuel into electric power that made the cost in 1950 only 78 per cent of what it was in 1900. It is his technical improvement which has reversed the trend in the price of fuel. Without that contribution the cost for fuel per kilowatt-hour today would be 460 per cent of the 1900 price instead of only 78 per cent.

The industrial steam plant also has a story to tell on the by-product generation of power. Typical heat

TABLE NO. 4

THERMAL PERFORMANCE OF "BY PRODUCT" STEAM ELECTRIC POWER PLANTS

OF HISTORICAL SIGNIFICANCE

Expressed as net plant heat rate in Btu per kwhr chargeable to power, for representative installations from 1900 to 1950.

Byproduct plant with 50% boiler eff; 80% generator eff; 5% auxiliary use.	1900	9,000
Byproduct plant with 80% boiler eff; 90% generator eff; 5% auxiliary use	1925	5,000
Byproduct plant with 88% boiler eff; 97% generator eff; 5% auxiliary use	1950	4,200

rates are shown in Table 4. A comparison of these data with those of Table 3 or Fig. 1 shows (1) the much better performance which prevails with by-product generation than with condensing generation, and (2) the changes which have occurred over the years. The improvement in thermal performance has not been as great with industrial by-product plants as with condensing electric utility plants. The data of Table 6 show the nature of the improvement on a comparative basis. With good utility plants a heat rate of 50,000 Btu per kwr in 1900 became 15,000 in 1925 and 10,000 in 1950; but for the by-product industrial plant a heat rate of 9,000 in 1900 was reduced to 5,000 in 1925 and to 4,200 in 1950. The difference in Btu per kwhr between the two methods of steam-electric generation is shown in the last column of Part 1 of the table. In 1900 there was a margin of 41,000 Btu per kwhr in favor of by-product power. By 1925 this margin had been cut to 10,000 Btu and today it has shrunk to a value of less than 5,800. Or, if a price of 30 cents per million Btu were assigned to fuel, then the comparative fuel costs and their differences would be as given in Part 2 of the table.

Increased Use of Central Station Power

The difference of 12.3 mills per kwhr in 1900 has been reduced to 1.74 mills in 1950. It is this kind of performance which has contributed to an increasing use of central station power by industrial plants and a decreasing proportion of self-generated power by industry. Thus before World War I industry purchased about one-sixth of its power needs whereas today it purchases nearly two-thirds of its requirements.

The size of plants and of units has increased over the years to a striking extent. Boilers have grown from hand-fired operations burning perhaps a half ton or a ton of coal per hour through the era of mechanical stokers, to the modern pulverized coal designs which consume coal at a rate in excess of a ton a minute. Prime movers have grown similarly from the largest reciprocating engines of 7500-kw capacity at the turn of the century to steam turbine-generator units with ratings in excess of 200,000 kw. The speeds of these prine movers have gone from 75 rpm to 3600 rpm. In some respects this speed of 3600 rpm, set by the electrical specification, constitutes an impediment to further progress.

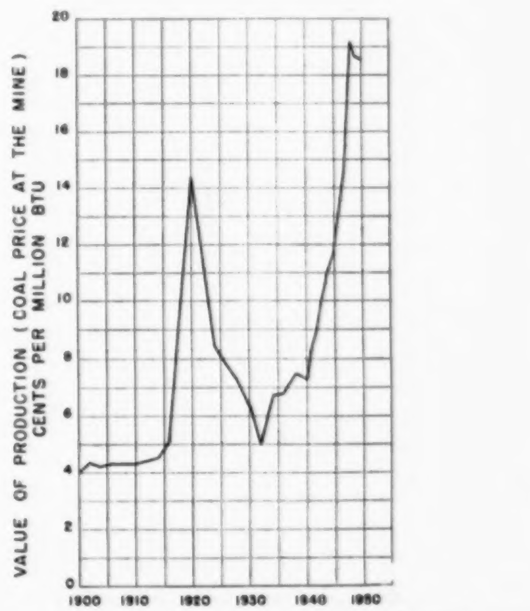


Fig. 2—Value of production (coal prices) for the bituminous coal and lignite mining industry in the United States, 1900–1950

(Adapted from the Bureau of Mines Minerals Yearbook

Modern large turbines are now usually supplied by steam on a unit basis, i.e. one boiler serving one turbine. This is in contrast to the prevalent arrangement of 25 or 50 years ago, where as many as a hundred boilers, arranged in batteries, and sometimes in double decks, supplied steam to a loop header system so that from this common header a half dozen or more turbines or engines might be served. Development of the unit system, without spare boilers, and in ever-increasing sizes has led to such improvements in the use of space as to reduce the building volume requirements as shown by Table 7. Thus since the peak of development for the steam engine (1900) to the plants being built today for 100,000–200,000-kw units the building volume has dropped from 300 to 25 cu ft per kw of capacity. Floor space has dropped in the same period from 2.5 to 0.2 sq ft per kw of capacity. These reductions in building volume and floor space have contributed greatly to keeping the investment cost of plants within bounds. Despite

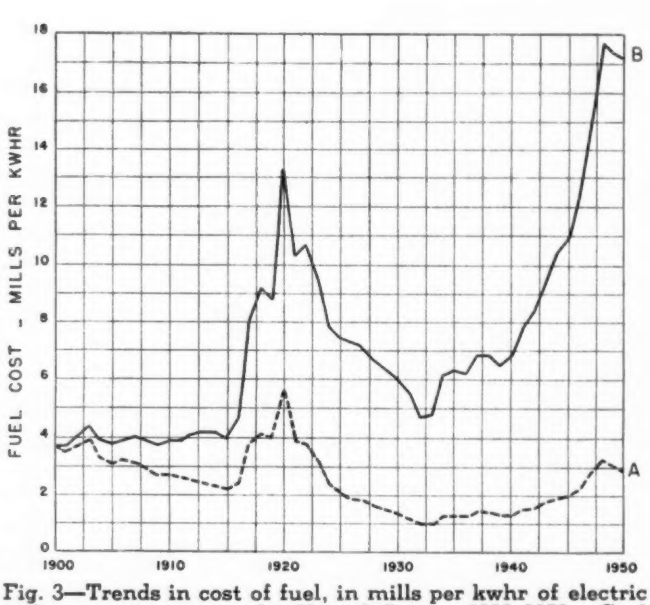


Fig. 3—Trends in cost of fuel, in mills per kwhr of electric utility generation in the United States, 1900–1950. Coal mine prices as in Table 5; coal heat value 13,000 Btu per lb. Equivalent average fuel consumption or heat rate as in Fig. 1

Curve *A* shows electric energy cost using prevailing heat rate and fuel price for each year.

Curve *B* shows what the cost of electric energy would have been if the heat rate for the year 1900 had prevailed throughout the period but employing the coal price for each specific year.

the rising prices for power house buildings these reductions in space requirements have leveled down on the cost in dollars per kilowatt.

Many designers have given this building cost the closest attention and have perfected constructions which place much of the equipment out of doors. This practice has found especial favor in the temperate parts of the country. Where the climate is more rigorous a partial outdoor construction has been developed. Some elements of plants, especially the electrical galleries and substations, have moved in almost all cases from indoors to outdoors. This trend for the entire power plant will probably continue because many designers have been forced by prohibitive prices to abandon elaborate buildings and to substitute some less expensive, functional

TABLE NO. 5

VALUE OF PRODUCTION (COAL PRICES) FOR THE BITUMINOUS COAL AND THE LIGNITE MINING INDUSTRY

UNITED STATES 1900 - 1950

Adapted from Bureau of Mines Minerals Yearbook

Year	Production Million tons	Value of Production at Mine $ per ton	Value of Production at Mine ¢ per Million Btu
1900	212	1.04	4.
1902	260	1.12	4.3
1904	279	1.10	4.2
1906	343	1.11	4.3
1908	333	1.12	4.3
1910	417	1.12	4.3
1912	450	1.15	4.4
1914	423	1.17	4.5
1916	503	1.32	5.1
1918	579	2.58	9.9
1920	569	3.75	14.4
1922	422	3.02	11.6
1924	484	2.20	8.5
1926	573	2.06	7.9
1928	501	1.86	7.2
1930	468	1.70	6.5
1932	310	1.31	5.0
1934	359	1.75	6.7
1936	439	1.76	6.8
1938	349	1.95	7.5
1940	461	1.91	7.3
1941	514	2.19	8.4
1942	583	2.36	9.1
1943	590	2.69	10.3
1944	620	2.92	11.2
1945	578	3.06	11.8
1946	534	3.44	13.2
1947	631	4.16	16.0
1948	600	4.99	19.2
1949	438	4.88	18.7
1950	512*	4.85	18.6
1951			

*Preliminary - Based on coal with average heating value of 13,000 Btu per lb.

type of structure. And it is only reasonable to expect still further efforts to reduce the cost of the enclosing structures more and more.

The advent of the large unit and the development of the "one boiler serving one turbine" design has also had its repercussions on the labor requirements for the operation and maintenance of the generating plants. Despite the introduction of the 40-hr week the personnel required to run a steam-electric power plant has been so reduced that today one man will handle 2500 kw of capacity whereas with the last work in reciprocating engine practice in 1900 one man was required for every 90 kw of capacity. This reduction has not been achieved by increase of size alone. The reliability of the equipment and the perfection of automatic controls have also contributed to the labor record. The factor of relia-

TABLE NO. 6

COMPARATIVE IMPROVEMENT IN THERMAL PERFORMANCES OF STEAM ELECTRIC CENTRAL STATIONS AND INDUSTRIAL "BYPRODUCT" STEAM POWER PLANTS

1900 - 1950

Expressed as net plant heat rate, Btu per kwhr in Part I, and as Fuel cost, mills per kwhr (30 cents per million Btu fuel price) in Part II.

PART I

Overall Plant Heat Rate Btu per Kwhr send out for Typical Plants

Year	(1) Central Station	(2) Byproduct'Plant	Difference Between (1) & (2)
1900	50,000	9,000	41,000
1925	15,000	5,000	10,000
1950	10,000	4,200	5,800

PART II

Fuel Cost in Mills per Kwhr (based on 30¢ per MMBtu for fuel)

Year (Equivalent)	(1) Central Station	(2) Byproduct Plant	Difference Between (1) & (2)
1900	15.00	2.70	12.30
1925	4.50	1.50	3.00
1950	3.00	1.26	1.74

TABLE NO. 7

BUILDING VOLUME AND FLOOR SPACE REQUIREMENTS

OF REPRESENTATIVE STEAM ELECTRIC GENERATING PLANTS

1900 - 1950

Plant	Year	Plant Size Kw	Building Volume cu ft per Kw	Floor Space sq ft [illegible]
74th Street I.R.T. Reciprocating Engine Plant	1903	45,000	180	2.0
Good steam turbine plant, World War I	1918	100,000	40	0.3[illegible]
Good steam turbine plant, post World War I	1925	150,000	35	0.2[illegible]
Good Steam turbine plant, World War II	1945	200,000	30	0.22
Good steam turbine plant, post World War II	1950	300,000	25	0.20

bility of equipment should not be treated too lightly. Steam turbines, of large size, have case histories showing more than 50,000 hr of service before the shell has been opened for inspection or maintenance. Boilers have likewise been improved. These greater reliability expectations should lead to the further development of large size equipment and to the reduction of the need for spare capacity and reserves.

One of the important contributions, which have done so much for the improvement of steam plants, is the better understanding of the requirements for proper control of the quality of boiler feedwater. Water purity is a matter which needs the closest supervision by competent chemists. This control of water quality embraces all such items as the usual suspended solids and hardness but also the oxygen content, the hydrogen-ion concentration, and the silica content. Acceptable commercial methods are in regular use on these items so that even in the industrial by-product power plant, with 100 per cent makeup, the highest steam pressures can be used. This has greatly extended the potentialities of the by-product plant because with high throttle pressures it is possible to get high ratios of power to process steam.

Fig. 4 is an attempt to forecast future loads, based on the data of Tables 1 and 2, projected for load growths of 3 to 8 per cent (broken lines) modified by population growth (solid lines). This study indicates an annual electric utility output of around 1000 billion kilowatt-hours by 1970 with an installed capacity of 200 million kilowatts.

Whatever values that are accepted as a reasonable estimate of the power load by 1970, it is evident that the engineering profession has a vast development program ahead of it. The logical questions are: (1) How will these expected loads be met? (2) What kind of generating plant will be built? (3) What will be the source of energy to deliver these capacities? The prospects must, of course, include all sources of raw energy, such as elevated water supply, fossil fuels, the wind, the tides, the sun's rays, and nuclear fuel. Any rational analysis undertaken to cover the next fifteen or twenty years must proceed on the realities. It cannot get very far from the realm of actuality and into the areas

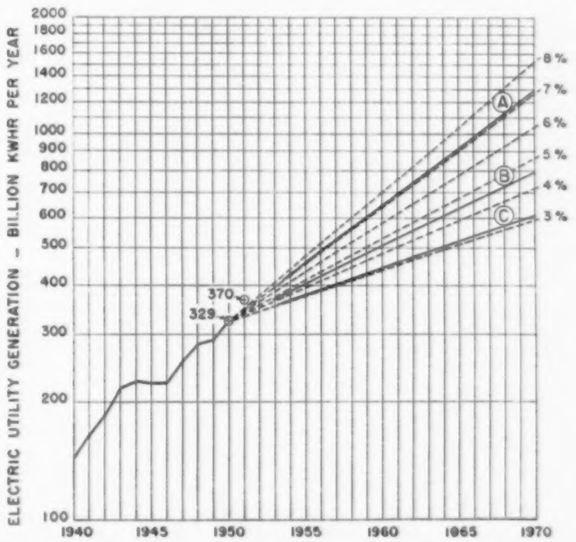


Fig. 4 Estimated annual electric utility output to 1970 in U. S.

Broken lines show annual growth rates of 3 to 8 per cent as applied to 1950 generation of 329 billion kilowatt-hours. Solid lines show growth rates as related to population. Curve *A* is from the extrapolated per capita consumption trend of the last three decades. Curve *B* is from the same per capita consumption growth as prevailed during the 1940–50 decade. Curve *C* is from the average per capita consumption of the last three decades.

of unalloyed imagination. This means that the emphasis in the near future will continue to be upon water power and fossil fuels, especially coal.

Some progress can be anticipated in the direction of atomic power and there will doubtless be increasing efforts to find ways of harnessing, practically, the sun's energy. The main reliance, certainly for the immediate future, will be on hydro and fuel. It is likely that our liquid fuel economy will reserve more and more of our petroleum for transportation services because of its tremendous merit with the portable power plant. The stationary plant will have to rely increasingly on coal. This translates rigorously, in today's thinking, as steam power. While there are encouraging signs that there are other mechanisms on the way for converting the heat energy of coal into electric energy, steam power appears to be the one reliable and economical system which will dominate the immediate future.

An attempt has been made to translate the expected loads into fuel and water requirements. The data

TABLE NO. 8

ESTIMATED THERMAL POWER GENERATION FOR THE YEAR 1970 REQUIRED TO MEET THE NEEDS OF THE ELECTRIC UTILITY INDUSTRY OF THE UNITED STATES AFTER ALLOWANCE FOR HYDRO ELECTRIC GENERATION

Hydro capacity of U. S. from Federal Power Commission 31st Annual Report, pp. 72 and 73; 1952.

Presently installed	-	18,700,000 kw
Estimated undeveloped	-	87,600,000 kw
Estimated ultimate development	-	106,500,000 kw
Estimate Annual output of ultimate development	-	487×10^9 kwhr in an average year.

These data are combined with estimated total energy requirements for the Year 1970 from Fig. No. 6.

Annual Growth %	Total Required Electric Output Billion Kwhr	Output in Kwhr Required from fuel if hydro capacity is developed.				Percentage annual output from fuel if hydro capacity is developed.			
		100%	67 %	50%	33 %	100%	67 %	50%	33 %
3	600	-	-	357	438	-	-	60	73
4	720	-	-	477	558	-	-	66	78
5	880	-	556	637	719	-	63	72	82
6	1050	563	726	807	888	54	69	77	85
7	1250	763	926	1007	1088	61	74	81	87
8	1530	1043	1206	1287	1368	68	79	84	89

of Tables 8 and 9 are the consequence of this attempt. In allocating future generation between hydro and steam it must be recognized that firm, prime and peak capacities confuse the issue. In a similar way it must be evident that the more advantageous hydro sites have already been harnessed. Each time that another site is developed, what remains is less attractive than what was available before. And in turn, much of the potential hydro capacity is not properly located with reference to the market, that is some 40 per cent of the nation's potential hydro is located in the Pacific Northwest.

Of the many efforts which have been made to estimate the aggregate potential hydro capacity of the country the most recent and most reliable is that of the Federal Power Commission which places the figure at 106,500,000 kw and a production of 487 billion kilowatt-hours in an average year. The existing water power development is 18,700,000 kw with an average annual output of 97 billion kilowatt-hours. The hydro capacity of the country is thus developed to 17.5 per cent of the power potential and 20 per cent of the energy potential.

TABLE NO. 9

ESTIMATED ANNUAL FUEL REQUIREMENTS FOR THE YEAR 1970

TO OPERATE THE ELECTRIC UTILITY PLANTS OF THE UNITED STATES

Estimates predicated on

1. 75% of annual generation to be by fuel.
2. 80% of fuel generated power to originate in coal.
3. Annual average heat rate - 10,000 Btu per kwhr.
4. Average heating value of coal burned - 12,500 Btu per lb.

Annual Growth Rate	Total Electric Output	Electric Output Generated By Fuel	Total Fuel Required Expressed as Equivalent Coal	Estimated Coal Required
%	Billion Kwhr	Billion Kwhr	Million tons	Million tons
3	600	450	180	144
4	720	540	216	173
5	880	660	264	212
6	1050	790	316	253
7	1270	950	380	304
8	1530	1150	460	368

When such figures as these for the hydroelectric capacity of the nation are combined with the anticipated load growth data some interesting results are obtained. In Table 8 an attempt has been made to set up the figures for water- and fuel-generated electric energy for the year 1970. Various percentages of hydro development have been postulated and deducted from the expected total requirements in order to estimate the contribution which must come from fuel. The location of many hydro sites, far removed from markets, makes much of the potential capacity fictional. If the 6 per cent growth rate (1000 billion kwhrs by 1970) is taken as representative, the data of the table demonstrate the utter inadequacy of water power to meet our demands for electric energy. If one-third of the energy has its origin in hydro nearly seven-eighths of the total must come from some other source—probably fuel.

The increasing inadequacy of water power for future needs is already recognized in many parts of the country. There are utility systems which started out exclusively as hydro only a few decades ago and which today have become predominantly steam. The Tennessee Valley Authority, which was the prime example of a hydro system, burned 900,000 tons of coal in 1950 but is expected to burn 13,000,000 tons in 1956—an increase of nearly 1500 per cent in coal consumption in a period of six years. This is not exceptional as there are many other examples which might be cited similarly to demonstrate the increasing importance of steam power and the lessening importance of hydro power.

In an effort to translate the data of Table 8 into an estimate of the fuel requirement for the electric utilities by the year 1970, Table 9 has been prepared. The procedure used in the development of this table has been to apply the following basic estimates:

(1) 75 per cent of the annual generation will originate in fuel.

(2) 80 per cent of the fuel-generated energy will originate, in turn, in coal.

(3) The annual average plant heat rate by the year 1970 should be reduced to a value of 10,000 Btu per kwhr.

(4) The average heating value of coal burned should be 12,500 Btu per lb (25×10^9 Btu per ton).

The results of the application of these figures to the anticipated load growths of 3 per cent to 8 per cent are shown in the last column of the table. For the growth rates previously emphasized the utilities are estimated to need between 200 and 300 million tons of coal annually by the year 1970. Last year the utilities used somewhat more than 100 million tons. The entire bituminous coal demand of the nation for the year 1952 is estimated as 560 million tons. A comparison of the expected consumption of 200 to 300 million tons by the year 1970 with this figure of 560 million tons poses many serious problems for our industrial economy. These data make no allowance for the growth in industrial demands, in heating demands, and in the possible conversion of coal to liquid fuel forms in order to buttress our petroleum reserves.

One further observation can be made from these estimates on fuel. For every kilowatt-hour generated in a steam plant today, at a heat rate of 15,100 Btu, there is required approximately 750 lb of water in the condenser circulatory system. By the year 1970 the anticipated fuel consumption of 300 million tons will call for an average water supply requirement of the order of 200,000 cu ft per sec. With a 50 per cent load factor the peak flow rate would run to 400,000 cu ft per sec. If this were potable water it would be sufficient to sustain a population of billions of people. This condensing water requirement, while large in magnitude, is alleviated by tide-water operations, by reuse of the water in flowing streams after sufficient evaporative cooling, and by reclamation systems such as cooling towers and spray ponds. The non-uniform distribution of water resources also poses a question here for the steam plant as it did above for the hydro plant.

The future of steam power for electric energy generation thus presents our industrial economy with many new problems. If we are to meet the demands for electric power, the burden will in all likelihood be borne in the next few decades by steam. That burden is, in turn, promptly shifted to the people and the industries concerned with providing the fuel and the water. What steps can and should be taken to meet the impact of the relentless pressure of our steam power plants on the nation's coal and water resources?

Heard at the ASME Annual Meeting

With a record attendance approximating some 6500 registrants, the Annual Meeting of the American Society of Mechanical Engineers was held at the Statler and McAlpin Hotels, New York, November 30 through December 5. Affiliated with the ASME meeting was that of the American Rocket Society. The program included more than a hundred sessions comprising nearly three hundred technical papers in addition to a number of panel discussions on selected topics, speeches at luncheons and the annual banquet on Wednesday at which the guest speaker was Charles F. Kettering, research consultant of General Motors Corporation, whose subject was "The Engineers' Responsibility in Educating the Public."

The banquet was the occasion for the conferring of honors and awards. These included the Daniel Guggenheim Medal to Sir Geoffrey De Havilland, pioneer in the design of aircraft; the Richards Memorial Award to Jess H. Davis, president of Stevens Institute of Technology; the Worcester Reed Warner Medal to Max Jakob, heat transfer consultant; the Melville Medal to Professor Neil P. Bailey of Rensselaer Polytechnic Institute for his paper on "Flow and Combustion Stability"; the ASME Medal to Nevin E. Funk, former vice president of the Philadelphia Electric Company, for achievements in economic operation of interconnected power systems; the Holly Medal to Sanford L. Cluett for his invention of sanforizing; the Pi Tau Sigma Gold Medal to Hubbert L. O'Brien, assistant manager of research for the Graver Tank & Mfg. Company, for outstanding achievement in mechanical engineering within ten years after graduation; and the Junior Award to Warren M. Rohsenow for his paper on "A Method of Correlating Heat Transfer Data for Surface Boiling of Liquids."

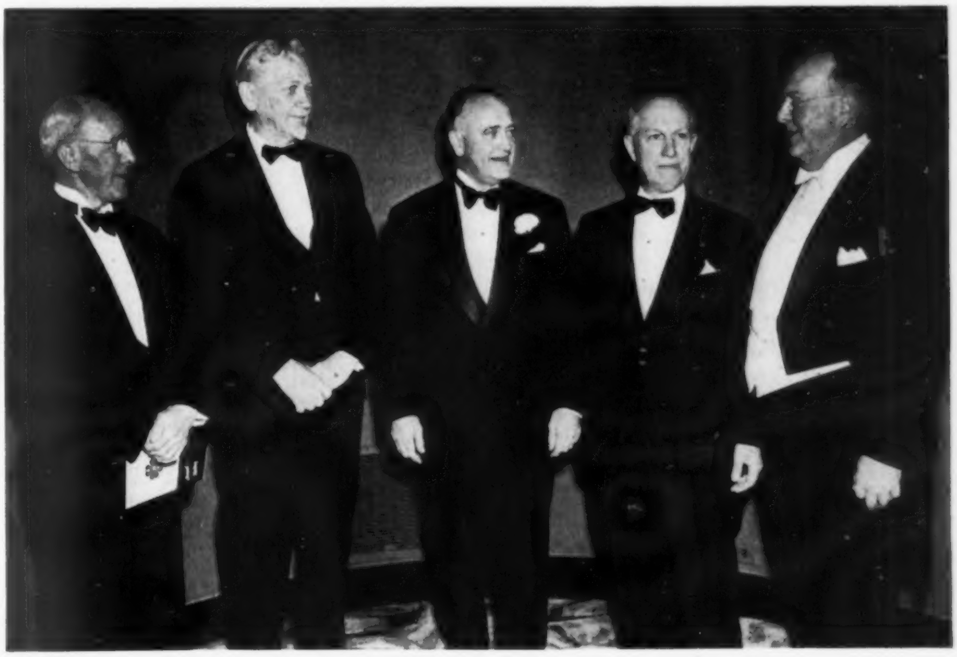
At the president's luncheon on Monday, President R. J. S. Pigott reviewed some of the activities of the Society which now has some 37,000 members plus 10,000 student members. He referred to the fact that it now has 33 subcommittees working with standards of various sorts and eight committees concerned with safety standards. He saw and urged greater participation of engineers and engineering societies in government activities, especially in view of the increasing technical aspects of government operations.

Quick Starting of Large High-Pressure, High-Temperature Boilers

A paper of which **J. C. Falkner** was a co-author was presented at the 1947 Semi-Annual Meeting describing a procedure for reducing thermal starting-up stresses with the quick starting of large high-pressure steam turbines. This was followed in May 1949 by a paper before the Metropolitan Section (New York) reviewing experience in quick starting of both turbines and boilers at several plants of the Consolidated Edison Company. Further progress was reported at the 1950 Spring Meeting.

The present paper by Mr. Falkner, based on a large number of tests with nine large high-pressure, high-temperature boilers of four different designs, shows that safe operating procedures can be developed to bring a million-pound-per-hour boiler from cold condition to on-the-line in one to two hours. Some of these boilers were on a unit system with a topping turbine; some on a unit system with a condensing turbine; and some on bypasses to lower pressure systems.

This has been accomplished without shortening the normally expected superheater tube life and with drum tangential and radial stresses less than those incurred during slow starting, except at the drum ends where the measured stresses were greater in the quick start. It is believed that minor changes in drum internal baffle



Left to right: Sanford L. Cluett, vice-president, Cluett, Peabody & Co.; S. P. Timoshenko, who was made an honorary member; the incoming president, Frederick S. Blackall, jr.; John M. Lessells, M.I.T., also made an honorary member; and Nevin E. Funk, who received the ASME Medal.

arrangement would reduce these stresses to within allowable Code values.

The author expressed the opinion that one hour starting of such units, while apparently not the minimum possible, is a reasonable time in which to permit a complete check by the operators.

Discussions

In discussing Mr. Falkner's paper, **B. J. Cross** of Combustion Engineering-Superheater, Inc., cited the old recommended procedure of adhering to a temperature rise of 100 deg F per hr, observance of which would call for a period of four to six hours to put a cold boiler in service. The only justification of this, he said, was that boilers have been so started for years without any evidence of damage. It would appear, however, from the rather convincing evidence reported by Mr. Falkner that large steam generating units can be put into service in a very much shorter time with at least equal safety.

Mr. Cross pointed out that a most important factor resulting in the more favorable conditions over the shorter starting periods for boilers is a uniform firing rate and a more uniform application of heat over the periphery of the furnace, as in the case of the Sherman Creek boiler, the walls of which constitute the principal evaporative heating surfaces. Moreover, the higher rate of firing should have the effect of promoting a better thermal circulation up to the period when the boiler begins to deliver steam, this thermal circulation being dependent upon the temperature difference between riser and downcomer circuits.

Finally, present-day steam generating designs are more favorable to rapid starting because the major part of the evaporative surface is ahead of the superheater. Since the rate of firing during quick starts is about 20 per cent that of full-load firing, the gas at the superheater can be kept below a temperature that might endanger the superheater elements, and steam flow that affords further protection to the superheater can be promoted early in the starting period.

W. H. Rowand, of Babcock & Wilcox Company, observed that even heating and expansion of the furnace and convection enclosure walls is of particular importance when the setting and casing are integrally attached to the pressure parts and adjacent walls are tied together, such construction being generally used in boilers whose furnaces operate under pressure.

As to the drum temperatures during starting up, one of the most important stresses set up is the circumferential stress at the outer surface due to the drum being hotter above the water level than below it. The total is a summation of the design pressure stress plus that due to the temperature difference between the top and bottom. It should be kept below 90 per cent of the yield point during starting. The design should be such as to minimize the possibility of stagnant water or air pockets forming and making sure that hot or cold spots are not produced by localized injection of steam or cold water. Moreover, connections between the drum and other parts of the boiler should possess sufficient flexibility.

A third prepared discussion of Mr. Falkner's paper was offered by **A. R. Weismantle,** of Foster Wheeler Corporation, who, after commenting on certain details shown in the charts, offered the following general comments:

1. That quick starts should be made only with furnace heat input constant and uniformly distributed. Measurement of gas temperature entering the superheater then becomes a most important indication of superheater safety.
2. Design details at drum ends should be such as to minimize temperature differentials during quick starts. However, a full evaluation of stresses involved during expansions can only be made with a full knowledge of a particular unit arrangement and a comparison of measured versus expected expansion for any start.
3. That operators should know they will not obtain as much fuel saving for quick starts from cold as they might be led to expect because the setting and casing, also heavy parts such as the drums, will not reach equilibrium temperature during one-hour starts. That is, the setting and casing alone account for 10 to 15 per cent of the total heat required to bring a large unit to operating conditions, and only a small portion of this heat is provided in the first hour.
4. While agreeing with Mr. Falkner's basic concept that boilers can be safely quick-started in one or two hours, Mr. Weismantle emphasized that differences in design require careful testing of each unit at vulnerable points in establishing the procedures.

Quick Starting of Turbines

With reference to the quick starting of turbine-generators, **C. W. Elston,** of General Electric Company, observed that despite development of steels with greater high-temperature strength and creep resistance, the higher initial pressures now in use require turbine casings and valve casings of greater thickness to resist bursting forces. The most important effects of temperature change he listed as follows:

1. Thermal stresses in external valve bodies, integral valve chests and turbine casings
2. Thermal stresses in rotors
3. Differential expansion between the rotating and stationary parts
4. The effect of temperature differentials between flanges and flange bolts on the adequacy of turbine casing flanges

It is assumed, of course, that the starting of the turbine is preceded by operation on the turning gear for a sufficient period.

In the past, starting and loading instructions generally have involved a maximum rate of metal temperature rise of 500 deg F per hr, but with greater casing wall thickness it seems prudent to keep rates of temperature change somewhat lower, depending upon initial pressure and temperature. To this end a revision in the recommendations was suggested.

Furthermore, it was pointed out by Mr. Elston that for turbines containing austenitic valve casings and turbine casings, the rate of metal temperature change on these parts should be limited roughly to one-fourth of that allowed for ferritic materials for the same risk of producing permanent distortions. Austenitic casing materials commonly in use have an elastic limit equal to approximately one-half that of ferritic casing materials.

As for the rotors, they do not appear to be adversely affected by rates of steam temperature change that might occur within reasonable limits. This is due to their inherent symmetry, the high quality of rotor forg-

ing, the care exercised in machining, and the employment of heat-indication tests to insure their thermal stability.

Central Station Construction Costs

"Central Station Construction Costs" was the theme of a Panel Discussion at the Tenth Power Session on Thursday afternoon. The participants were **Arthur Larnard,** civil engineer with Ebasco Services, Inc., whose topic was "buildings and structures"; **Herman Weisberg,** mechanical engineer of the Public Service Electric & Gas Company, New Jersey, who discussed "boiler costs"; **E. H. Krieg,** consulting engineer with Stone & Webster Engineering Corporation, who dealt with "turbines"; **H. A. Wagner,** of The Detroit Edison Company, who reviewed the influence of heat cycles on plant cost; and **R. W. Parkinson,** of Commonwealth Associates, Jackson, Michigan, who considered "coal handling."

Basically, the factors influencing construction costs are (1) type of plant, whether fully enclosed, semi-outdoor or outdoor; (2) materials used; (3) loading stresses to be figured (such as wind loads or earthquakes); (4) station substructure and circulating water tunnels; and (5) stacks and cranes. Steel frames and brick walls are now giving way in many cases to new types of construction, said Mr. Larnard, with prefabricated panels of concrete or sheet metal (steel or aluminum) finding increasing favor. They are much cheaper than brick walls because of the labor involved with the latter and can be used for architectural effects. Poured concrete is the more expensive, and concrete blocks are susceptible to cracks and moisture penetration unless coated. The trend is away from large windows and toward use of glass blocks or thermopanes. Where windows are used, aluminum sashes are popular.

In general, the structural engineering accounts for about 28 per cent of the initial expenditure.

Mr. Weisberg estimated the boiler plant as accounting for about 50 per cent of the total cost and that calculated performance must always justify any added expense. He recalled that power plant costs doubled shortly after World War I; then increased 60 per cent up to World War II and doubled again since the latter; so that at present prices a typical 1912 plant would now cost $400 per kilowatt of capacity. However, due to engineering progress in the interim, the average unit cost of present designs has been held to about $160 per kilowatt. Moreover, 1953 designs now under consideration show about 6 per cent improvement over those of 1951.

Increased size of units has been a large factor in holding down cost, despite increased fuel, material and labor costs. Also, a competitive situation between manufacturers of equipment has been a contributing factor.

The speaker mentioned that steam temperature of 1200 F and pressures above the critical, with two stages of reheat, are now being studied as a possible further step.

Mr. Krieg expressed the opinion that kilowatt-hour cost is as important to consider as is first cost, for it involves availability. Maximum guaranteed capacity should be used to the fullest extent, as applied to all component equipment, inasmuch as the greater capability will reduce the initial cost per kilowatt. Also, larger units mean lesser unit costs. He mentioned that the Preferred Turbine Standards are now being revised to include only the maximum guaranteed rating.

Maximum capacity can be stretched by eliminating the top bleeding point and by lowering the back pressure. In fact, it should be possible to stretch the capacity some $7^1/_2$ to 10 per cent without cutting into safety. To insure top capacity both the turbine and condenser should be kept clean and in the best possible condition. For this purpose a monthly checkup is recommended.

Further suggestions offered by Mr. Krieg toward reducing investment costs were to minimize piping runs; select the highest steam conditions in the group of turbine sizes offered; carefully analyze the cost of turbine types for the particular conditions; and save erection costs by erecting units in sequence.

Mr. Wagner cited the widespread adoption of the reheat cycle and compared station heat rates of the reheat and straight condensing cycles. He showed why it was found more economical to employ six instead of seven stages of feedwater heating for his company's new St. Clair Station. Double reheat for 1800 psi, 1000 F initial conditions would provide from 2 to $2^1/_2$ per cent gain, but it could not be justified. He suggested that multiple reheat at the turbine with liquid metal, such as is being employed for nuclear power, is a future possibility.

Contrary to the situation with certain other equipment, Mr. Parkinson observed that large boilers have very little effect in reducing the cost of the coal-handling system. Such costs on a unit basis vary widely, from $4 to $18 per kilowatt, depending not only upon the system employed but also as to whether it is laid out with a view toward serving the initial or ultimate plants. Twelve dollars per kilowatt may be taken as a reasonable figure for the typical installation. Progress has been attained in increased reliability and cleanliness, and the speaker suggested that spare drives be provided where a single-belt installation is concerned. In some cases initial provision is made for installation of a car dumper at such time as it can be justified by capacity extension. Also, much can be said for larger coal bunkers that permit coal handling on five days of the week only. There is a distinct trend toward use of bulldozers and scrapers in place of overhead bridges.

Industrial Power Plant Costs

Starting off a symposium on power plant costs was a paper entitled "Economical Industrial Power Plant Design" by **C. S. Robinson** of the du Pont Company. The mental approach of the engineer is one of the most important factors in industrial power plant design, particularly because of the danger and influence of personal prejudices, preferences and habitual ways. Rather than using preconceived ideas of what an industrial power plant should contain, it is more factual and more effective to begin with the minimum amount of equipment to supply the required needs and then to add only those items which can clearly be justified on the basis of an acceptable return on the additional investment. Another consideration is that there should be at hand basic process

data and that these should include no safety factors except as are explained. This is to avoid the possibility of constructing an economical boiler house which has unneeded and excess capacity involving an additional investment paying no return. Because of rapid changes in the art, provisions for future expansion should be clearly specified in terms of the probable time at which the expansion will be needed. Otherwise the excess investment may be highly uneconomical on account of subsequent engineering developments.

In trying to design low cost facilities the end result may be unconventional and meet with an understanding reluctance on the part of operating personnel. However, excellent cooperation from this important group can be had if the facts for the new design are clearly established and properly presented.

The second paper "Industrial Power Plant Construction Since World War II," was prepared by **T. A. Fearnside** and **F. C. Cheney** of Stone & Webster Engineering Corporation and presented three simple factors which can be applied to major equipment item costs to obtain a rapid estimate of total project costs. Factors of this type are especially useful to the consulting engineer who may be called upon to give a quick estimate for a client who is contemplating a power plant addition or expansion program. Unfortunately, there is no simple relationship between boiler capacity and amount of power generated in an industrial power plant, and so it is desirable to have a reliable method of estimating total cost based upon manufacturers' proposals for such items as boilers, turbines, condensers and switchgear.

The authors made a study of 10 industrial projects built within the last 6 years. These were of varying types and sizes, represented all conventional methods of firing, and had steam conditions in the range from 275 psig, saturated, to 1300 psig, 900 F. They arrived at a factor consisting of a multiplier by which a single manufacturer's estimated purchase cost may be increased to obtain an approximate erection cost of the portion of the project relating to the major equipment item concerned. It should be noted, however, that such items as excavation and foundations, yard piping and electrical feeders, special water plants, building structure and outside fuel and ash handling facilities are not included. On the basis outlined previously, average factors were derived, namely 3.61 for boilers, 1.69 for turbines and 1.86 for condensers. To be valid, these factors must be properly applied and supplemented by good engineering judgment as to the cost of miscellaneous additional items. In conclusion, the authors expressed the hope that others concerned with the design of industrial power plants would be willing to compare the results of this study with those obtained from their own investigations and experience.

F. G. Feeley, Jr. of Union Carbide and Carbon Corporation presented the third paper in the symposium. He pointed out that reliability and availability are the two most important criteria in industrial power plants and that his organization did not include any spare capacity in its plants because of the high availability of component equipment. New plants are constructed outdoors, and he indicated a preference for the pressurized-type boiler casing for this class of installation. Noting that steel for supporting of the deaerator at sufficient height to provide satisfactory head on the boiler feed pumps involves substantial costs, Mr. Feeley pointed to the use of subcoolers in connection with the deaerators as a means of locating them at or close to ground level. Among other things, the author favored elimination of certain spare auxiliary equipment and soot blowing apparatus exclusive of deslaggers.

The final paper in the symposium was presented by **John Campbell** of the du Pont Company whose subject was "Investment Costs—Industrial Power Plants." In determining individual boiler plant capacity, studies are made of the characteristic plant steam load and equipment is selected to permit uninterrupted operation during the colder winter months. However, there are some cases in which it may pay to curtail production during unscheduled outages rather than to carry additional boiler investment. He noted that at one plant a condition exists where it is more economical to install small boilers in various areas than to operate a central power house. In this instance, oil-fired package boilers are used, which require only structures around the firing end to house fuel burning and control equipment. These units also have other advantages, for they can be easily removed and used elsewhere as the plant expands, thus preserving utility of investment.

In industrial power plant design a close tie-in between the power engineer and those concerned with process requirements has a number of advantages. Familiarity with operating practices and process equipment permits the power engineer to specify materials of construction or equipment design which might otherwise be unfamiliar to him. On the other hand, he can call to the attention of the process engineer opportunities to make savings through practicing steam conservation and utilizing steam at the pressure and temperature most readily available from the power house. Unnecessary peaking of utility loads can be analyzed in terms of process variables, often with impressive reductions in excessive power demands. The association between the power and process designer also involves elements of competition between widely different viewpoints which enables both to maintain a flexible viewpoint and to take advantage of developments in other fields of engineering activity. In this type of collaboration, the end result should be a continual lowering of industrial power plant investment.

Spreader Stoker Furnace Heat Absorption

The fifth in the series of reports by the ASME Furnace Performance Factors Research Committee dealt with a spreader-stoker-fired steam generator located at the Whiting Plant of the Union Carbide and Carbon Corporation. Furnace heat absorption was determined from the temperature and composition of furnace exit gases in fifteen tests of a two-drum steam generator rated at 165,000 lb per hr at 915 psig, 740 F at the superheater outlet.

The first part of the paper, entitled "Furnace-Heat Absorption Efficiency as Shown by Enthalpy of Gases Leaving the Furnace," was presented by **J. W. Myers** and **R. C. Corey** of the Combustion Research Section of the U. S. Bureau of Mines in Pittsburgh. Furnace heat absorption

was determined by the difference between the net heat input and the heat losses, comprising the sensible heat and the products of combustion and the radiation of convection losses from the furnace casing. The tests were were set up to determine the effect of furnace heat absorption on variations of load, excess air, overfire air and slag and ash deposits.

From data obtained at the furnace outlet it can be shown that in this unit the distribution of gas temperature and excess air depended essentially upon the mass flow of flue gas through the furnace. At low mass flow rates the highest temperature occurred at the center of the outlet and the gradient was nearly uniform toward all of the walls. With increase in gas flow rate the high temperature zone extended gradually toward the rear wall and with the highest mass flow rates maximum temperatures were found at the rear wall. The variation in furnace exit gas temperature over the load range tested ranged from 300 to 1000 F. Although an attempt was made to correlate furnace heat absorption efficiency with net heat available and excess air, this proved unsatisfactory, due, it was believed, to slag and ash deposits. Accordingly, heat absorption coefficients were corrected to theoretically clean-wall conditions by the use of slag and ash effectiveness factors.

The maximum corrected furnace heat-absorption efficiency was 61.3 per cent at low load, with 27 per cent excess air, and with 16.7 per cent of the air introduced over the fuel bed. The lowest efficiency, 48.1 per cent, was obtained at intermediate load, with 53 per cent excess air and with 14.7 per cent overfire air.

The second part of the test was entitled "Variation in Furnace Heat-Absorption as Shown by Measurement of Temperature of Exposed Side of Furnace Tubes" and was prepared by **F. G. Feeley, Jr.,** of Union Carbide and Carbon Corporation and **Earle C. Miller** of the Riley Stoker Corporation. The furnace heat absorption was determined by measuring the surface temperature of the exposed side of the furnace tubes. A test schedule was set up to obtain data at the nominal steam loads of 80,000, 120,000, and 160,000 lb per hr, each set of tests to be run at 25, 40 and 60 per cent excess air. All of these tests were run except that at the maximum load and 60 per cent excess air, where limited induced-draft fan capacity made tests impossible. Whenever feasible two runs were made at each load condition to ascertain reproducibility of data. Procedure was to bring the unit to the desired load and excess air conditions for each test and to adjust the requirements for the cinder-return and overfire air systems to give optimum operating conditions. No attempt was made to clean the furnace and boiler heat absorbing surfaces directly before the test as these surfaces were relatively clean. However, at the end of each test period the furnace wall ash coating at various elevation and sections was estimated by observation and recorded to provide data for assignment of slag-ash factors.

Extensive stack tests were run to determine stack dust loadings and combustible content in the refuse leaving the stack. Care was exercised to assure reliable stack dust loading measurements. Samples were obtained by traversing the stack, which is 7 ft in diameter and 80 ft high, at a level 54 ft from its base. Due to the very low stack dust loadings the weight of stack refuse sample collected was inadequate for analysis of carbon content. For calculating stack carbon loss the carbon content of the dust collector catch was used. A representative dust collector catch sample was drawn from each of the ten cinder-return lines at thirty-minute intervals.

The authors offered the following conclusions: The rating is the most important factor in overall heat-absorption but elevation of the various surfaces above the grate has the greatest influence on relative heat absorption of the walls. The rating has less effect on heat-absorption near the grate than at the top of the furance. At all loads heat-absorption in the walls decreases rapidly as the distance from the grate increases. Excess air for combustion affects average heat absorption at all loads but has little affect on heat-absorption near the grate. The slag-ash pattern is more stable and of less influence in spreader-stoker firing than in the pulverized-coal-fired-test units. Overfire air, when used within the limits of these tests, has negligible effect on furnace heat-absorption.

Discussion

Mr. Miller, in response to a question concerning the use of the Utiliscope for furnace viewing during the latter part of the test, reported that the action of the individual feeders could be observed on the television screen as well as the build up of the ash particles on the furnace walls. It was also possible, he added, to detect variation in size consist of the coal when fired, and this observation proved especially helpful to the regular operators who on their own initiative used it as an aid in firing. Although this equipment was not available for the first series of tests, it gives promise of meeting a need for an instrument to observe the amount of slag ash deposits. Whether this can become a quantitative as well as a qualitative tool useful for experimental observation remains to be determined.

Liquid Metal as a Heat Transfer Medium

In order to produce power from a nuclear reactor, it is necessary to increase the temperature of the reactor cooling system. There are restrictions against boiling in a reactor and although water can be maintained in a liquid state by pressurization, certain design difficulties are involved. Therefore, the low-melting-point metals, sodium and sodium-potassium alloy, were selected for such development at the Knolls Atomic Power Laboratory, Schenectady, N. Y. In addition to their low melting points, these metals have high boiling points, are thermally stable, and have suitable nuclear and heat-transfer characteristics. Their principal shortcoming is their low specific gravity ($^1/_4$ to $^1/_3$ that of water) which requires larger weight flows than water.

Development work on use of these metals was started in 1947 and to demonstrate their practicability for this use a test installation was designed and constructed and has been in operation for nearly three years at the Laboratory. This test installation was described and results given in a paper by **Thomas Trocki** and **D. B. Nelson,** both of the Knolls Atomic Power Laboratory staff.

The test unit contains two sodium to sodium-potassium intermediate heat-exchangers of different designs and two steam generating units—one supplied by Babcock & Wilcox, using natural circulation of water, and the other

supplied by Combustion Engineering-Superheater, Inc., utilizing forced circulation.

In the test system the sodium circuit is heated in an oil-fired heater (to simulate the reactor) and this heat is transferred through a heat-exchanger to the sodium-potassium secondary circuit which, in turn, serves as the heating medium in the steam generator. The test system was designed for a steam output of 6600 lb per hr at 435 psi and 760 F. The temperature of the sodium leaving the heater is 950 F and the rated flow is 100,000 lb per hr.

A companion paper on "Design and Performance of Liquid-Metal Heat-Exchangers and Steam Generators for Nuclear Power Plants" was presented under the authorship of **R. D. Brooks** and **A. L. Rosenblatt,** also of the Knolls Atomic Power Laboratory.

This paper dealt with the technique of using sodium and sodium-potassium as heat-transfer fluids; described in some detail the design and construction of the heat-exchangers and the steam generating units (both forced and natural circulation); reviewed the operating procedure involved; and gave the results of heat-transfer tests. Excellent heat fluxes up to 150,000 Btu per hr per sq ft were found possible despite the additions of the thermal resistances that must be introduced to provide extremely high reliability to equipment for nuclear power plants. No deterioration in heat transfer coefficients, due to fouling, was noted.

A third paper dealing with "Vorticity Heat Transfer in Molten Metals" was presented by **R. A. Kennison** also of the Knolls Atomic Power Laboratory. This was largely a mathematical treatment in which the transfer of heat is assumed analogous to the transfer of vorticity for turbulent fluid flow in a long straight pipe. Nusselt numbers are found and compared with other theoretical and experimental information, and a simple velocity profile equation is derived.

Pumps for Handling Liquid Metals

As a part of the development work on nuclear power, two designs of pumps were employed for handling liquid sodium and sodium-potassium. One, a mechanical pump developed by General Electric Company was of the single-volute, radial, centrifugal type with a specific speed of 926 rpm and capable of circulating 400 gpm of liquid metal at 750 F. This was described in a paper by **Philip M. Clark** of the Knolls Atomic Power Laboratory. The design is such as to tolerate no leakage of liquid metal at the shaft, although a small gas leakage is permissible. Two identical units were built and have operated successfully for several thousand hours.

The second type, described by **J. F. Cage, Jr.,** also of the Knolls Atomic Laboratory, operates electromagnetically. Such a pump is especially adapted to the requirements, inasmuch as it is usuable in any radioactive liquid metal system. It has no seals or stuffing boxes, no moving parts and is leakless. Such pumps employ the "motor" principle, namely, that a conductor in a magnetic field carrying a current which flows at right angles to the direction of the field has a force exerted upon it. In this case the fluid is the conductor and the force, suitably directed in the field, manifests itself as pressure. The author described several pumps of this general type that were investigated.

Single Retort-Underfeed Stokers

A group of three papers on the application of single-retort underfeed stokers was presented at the Tuesday evening session. These were: "Application and Performance of Single-Retort Underfeed Stokers" by **E. C. Webb** and **J. E. Atchinson** of the Iron Fireman Mfg. Co.; "Present-Day Thoughts on The Application of Single-Retort-Underfeed Stokers" by **W. J. Mosshart** of Westinghouse Electric Corp.; and "Industrial Application of Arches for Single-Retort Stokers" by **Prof. T. S. Spicer** of Pennsylvania State College, the last mentioned being largely in the form of slides.

The first of these papers defined the place of the single-retort underfeed stoker, in the face of competition from the spreader, as being best adapted to the following conditions:

1. The only commercial method of burning coal that provides satisfactory automatic operation on load cycles that include long banking periods or extended periods of very light load.
2. Especially adaptable to space heating loads.
3. Ability to maintain ignition over a relatively small portion of the grate surface (in the retort zone), and then to expand automatically the active burning area to handle full firing rate.

The authors further pointed out that it is important with such units to maintain accurate control of fuel-air ratio if high combustion efficiencies are to be maintained, and that the air-flow meter should be capable of accurate regulation throughout the full firing range, and be properly synchronized with the fuel-feeding mechanism.

Although under certain operating conditions smoke may be produced immediately following "on" periods of an intermittently operated unit, this can be avoided without the use of overfire jets if the firing rate is modulated through a sufficiently wide range to meet major changes in output requirements. Modulated control will also reduce flue gas loss, reduce maintenance and permit use of coals having lower ash-fusion temperatures.

Mr. Mosshart emphasized the low overall cost as a factor favoring the single-retort underfeed stoker, and stated that care in working out details of installation, as well as in establishing control of operation, will pay good dividends in overall economy and abatement of smoke.

"For normal load below 25,000 lb of steam per hour, or low load factor with capacity up to 35,000 lb per hr," where investment costs must be kept low, and where stack discharge must be minimized," he said, "the single-retort stoker is a logical choice for burning bituminous coal."

He added that with units 8 ft or wider, provision of water-cooled sidewalls in the form arches would im-

prove ignition, stabilize operation with thinner fuel beds, and permit operation with lower excess air.

Wood Burning in a Central Station

The municipal plant of the City of Eugene, Oregon, depends for its fuel largely upon waste wood from the production of Douglas fir lumber. This is available either in the form of sawdust, chips or hogged slabs, all passing through a $3^1/_2$-in. rectangular screen before being burned on two Riley rear-discharge traveling grate spreader stokers under a 175,000-lb per hr two-drum boiler. The wood, as received, averages about 48 per cent moisture which is increased or decreased in storage according to the season. The heating value on a dry basis is 8750 Btu per lb. The price delivered at the plant, per unit of 200 cu ft, is $1.70 for sawdust and $2.25 for hog. As a precaution against scarcity of the wood, the boiler is designed for burning coal, oil or gas as auxiliary or substitute fuel. Primary preheated air is supplied at 350 F and secondary preheated air, for the overfire jets, at 600 F. The cinders which are collected in a multiple-cone collector following the air preheater are pulverized and returned to the furnace 9 ft above the grates.

A paper by **R. B. Boals,** general superintendent of the Eugene Water & Electric Board, and **Dale Bumstead, Jr.** and **C. J. Judson**, both of the firm of Bumstead-Woolford, Seattle, described this installation in detail and presented the results of a series of tests conducted on this boiler (No. 3) in the fall of 1950. Steam pressure at the superheater outlet ranged from 580 to 621 psia and steam temperatures from 777 to 836 F, with efficiencies, depending upon load, from 54.2 to 68.8 per cent.

Commenting upon performance, the authors observed that operation has been satisfactory at continuous rates up to 190,000 lb per hr and that loads as low as 30,000 lb of steam per hour may be maintained. However, in order to maintain optimum excess air at such light loads the zone dampers have been equipped with hydraulic cylinders to permit rapid and exact adjustment, and operation under such conditions is with the rear two zones dampered off.

The paper also described an earlier, more or less experimental installation, of six pneumatic spreader stokers under No. 2 boiler at the same plant.

Turbulent Suspension Burning

Defining turbulent suspension burning as "showering particles of solid fuel downward from considerable height in a furnace, through relatively large quantities of highly turbulent gas and overfire air to effect flash drying, partial or complete devolatilization, ignition of residual fuel constituents and uniform distribution of the residual fuel to the grate surface, where combustion is completed through use of reduced quantities of undergrate air," **Otto de Lorenzi,** of Combustion Engineering-Superheater, Inc., reported on such a unit that has been in satisfactory service for more than twenty months. Operating data were presented covering a wide range in capacity while burning wet wood refuse or fuel oil, as well as low-volatile coals.

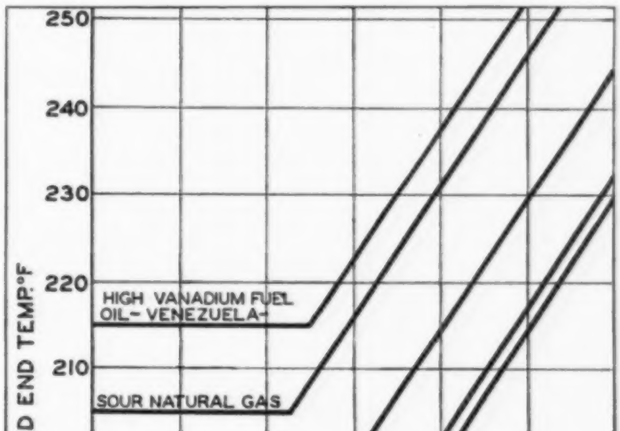
The effectiveness of this method of firing solid fuels is reflected in the performance attainable at apparent heat liberation rates per square foot of grate, exceeding those normally accepted as standard. Several other similar spreader-fired units are now under construction.

The author accompanied presentation of the paper with a motion picture showing actual operation within the furnace. This fully verified the points of the foregoing definition of turbulent suspension burning.

Design of Air Preheaters

In the paper entitled "Air Preheater Design as Affected by Fuel Characteristics," **Hilmer Karlsson** and **William Hammond** of the Air Preheater Corporation noted that sulfur content is the fuel characteristic which appears to control air-heater plugging and corrosion. While other fuel constituents contribute to the degree of the problem, their effectiveness depends upon the sulfur content. The presence of carbon in the flue gas may aggravate the corrosion problem so that the best combustion conditions must be carefully maintained.

Since in selecting air heaters for new installations it is not possible to predict with any certainty the type of fuel that will be available during the life of the application, the air heater design must incorporate controls that will maintain the cold-end temperatures within safe limits. The use of "Cor-Ten" or "Mayari-R" for the low-temperature surface and the use of cold-end baskets is recommended. Aluminum has not been successful in regenerative air heaters. Application of effective soot blowers using superheated steam or dry



Curves showing recommended minimum average cold-end temperature over range of operation for various fuels

compressed air permits control of deposit formation. In the event that circumstances result in serious deposit formation, provision for water washing of the heaters will provide an effective remedy. Consistent attention must be given to cold-end temperature of all conditions of operation and in this respect automatic controls should be considered.

In his efforts to provide maximum availability, the power plant designer should consider the following factors pertinent to specification of air heaters:

1. Select the air heater in accordance with the limits suggested in the accompanying figure for the fuel most likely to be used.
2. Provide metal temperature control with sufficient range to permit the proper metal temperature to be obtained when burning the poorest fuel likely to be considered and to provide adequate protection for low-load operation at low ambient temperatures.
3. Select the combustion air temperature as high as practical.
4. Provide sufficient range in metal temperature control to avoid falling below the recommended temperatures for any load or ambient condition. Automatic controls should definitely be considered.
5. Soot blowing should be provided using superheated steam or dry compressed air. Provisions for washing the heater should also be considered.
6. Another alternative is to select the air heater based upon the best fuel and provide for removal of a layer of the heating element in the event that a poor fuel is selected.

The authors stated that a report on a project sponsored jointly by the U. S. Bureau of Mines and their organization should be available in the near future. This report, which is based on an eight-year investigation covering field and laboratory testing of the suitability of a large number of materials, will deal with an analysis of problems encountered with low-temperature flue-gas corrosion deposits.

Superheater Tubing Materials for High Temperatures

The ASME Research Committee on High Temperature Steam Generation, in a paper by **C. J. Slunder, A. M. Hall** and **J. H. Jackson,** reported on a laboratory investigation at Battelle of superheater tubing materials in contact with synthetic combustion atmospheres at 1350 F.

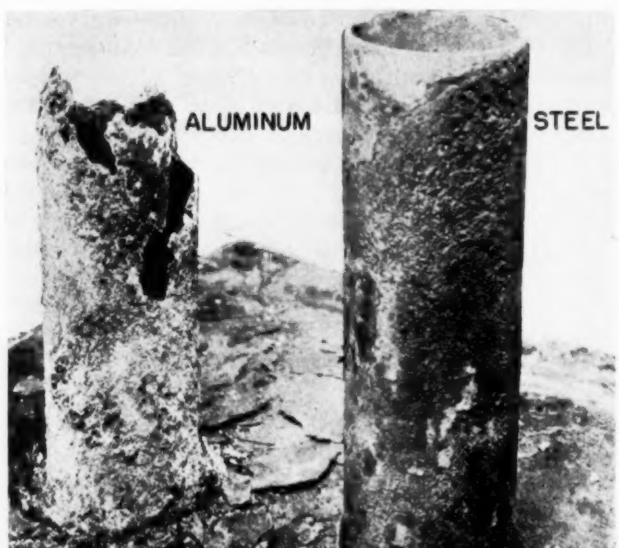
The resistance of twelve commercially available alloys to gaseous combustion products at 1350 F was evaluated in a series of eight 1000-hr laboratory tests. Two concentration levels of sulfur dioxide, carbon monoxide and alkali were employed in various combinations to determine the surface stability of the metals for superheater tubing at this metal temperature.

The best combination of low metal loss and minimum subsurface attack was shown by alloys of the 25 per cent chromium, 12 per cent nickel and the 25 per cent chromium, 20 per cent nickel types, although in the laboratory tests, the AISI 304 (18 per cent chromium, 8 per cent nickel) was also among the best on the basis of total depth of metal affected. The latter, however, was not confirmed by field tests.

A statistical evaluation of the metal-loss results indicated that the increase in corrosion caused by increasing the sulfur dioxide in the atmosphere from 0.02 to 0.20 per cent was significant. No importance could be attached to the minor differences caused by variation in carbon monoxide content up to 0.1 per cent by volume, nor to the differences obtained by partial immersion of the specimens in an alkali-metal-salt mixture during the tests. The mechanism of corrosion resulting from the presence of alkali metals in the fuels was stated to be a complex problem which requires further study.

Tubular Air Heater Problems

In a paper under the above title **E. F. Rothemich** and **G. Parmakian** of the Riley Stoker Corporation discussed the occurrence of air heater deposits and their effect on performance, maintenance and design. A practical method for establishing the safe temperature for any particular installation is to make a survey of the temperature of the surfaces under conditions of light loads and to compare these with the extent of the plugging and corrosion observed. Thermocouples should be attached to tubes which are known to be subject to fouling and corrosion and to other tubes which are known to be clean. The metal temperature of the clean tubes under this light load condition will indicate a safe temperature level. Somewhere between this temperature and the temperature of the tubes subject to plugging under the same conditions will be the minimum safe tube metal temperature for this particular installation. In general, it has been found that very little corrosion occurs at tube metal temperatures above 200 F and that corrosion is very rapid where the tube metal temperature falls below 150 F.



Comparative tube corrosion rates

Air heater deposits vary from soft soot to hard crystalline deposits which completely plug off a tube and form stalactites below the air heater tube sheet. The deposits are very hygroscopic so that once the deposit is formed absorption of acid is rapid and metal attack pyramids because of the increased insulating effect of the deposit. Fortunately, the deposits have high water solubilities and as such can be removed rather easily by hot water flushing. In a great number of natural-gas-fired installations corrosion occurs without the presence of deposits. The sulfur content of this fuel is very low and corrosion occurs at metal temperature levels found to be safe for oil- and coal-fired units. A large number of oil-fired units have their availability limited by the period between heater cleanings. In some instances the duration of the boiler outage is dependent upon the length of time required to clean the heater.

There are a number of methods for maintaining metal temperatures at the cold end of the air heater above minimum values which are known to cause corrosion. A number of these were discussed by the authors.

Gas bypassing of heaters is usually resorted to only in the case of very adverse fuels and where reduction in unit efficiency does not result in any appreciable economic loss. It is necessary to completely isolate an air heater from gas flow with the bypass in use, otherwise the stagnant gas in the heater tubes will be cooled by air passing over the heater and will result in very rapid corrosion. Since it is very difficult to completely isolate the gas side of an air heater from some gas flow this type of bypass is not a preferred method for control of corrosion.

Although a two-section air heater is a more costly arrangement and requires more space and fan power, it is a popular method. This arrangement permits easy repair of corroded tubes which by design are consigned only to the short cold end section of the heater. In like manner, the initial installation of short sections of tubes using air heater ferrules is another method used to permit easy maintenance of the heater.

Air heaters are normally constructed of low-carbon steel tubing. Other materials have been tested in an attempt to find a material that will better withstand the corrosion action in air heater tubing. The accompanying illustration shows an ordinary steel tube and an aluminum tube which has been placed in the breeching of a boiler for a period of four years. The metal temperatures averaged 150 F. Eastern bituminous coal with one per cent or less sulfur was burned on a single retort underfeed stoker. As can be seen, the aluminum tube is a complete failure, whereas the ordinary low carbon steel tube has lost only half of its wall thickness. Experience with aluminum tubes on a pulverized-coal-fired installation burning low volatile eastern bituminous coal with 2 to $2^1/_2$ per cent sulfur was similar and this installation returned to the use of steel tubes.

The authors reported that a research program has been underway for over a year using glass tubing. Special designs have been worked out for sealing the ends of the glass tubes in normal steel air heater tube sheets. No corrosion has occurred and the glass tubes have successfully withstood the abuses of vibration, expansion and handling. Corrosion resistant glass tubes can be strategically located in the critical outer rows of tube bundles and at the air entrance to heaters to prevent corrosion in these areas.

In conclusion it was urged that more attention should be given to the possibility of cleaning air heaters in service. Once plugging has occurred it is possible to remove the deposits by the use of hot water, since these deposits are mostly water soluble. When high sulfur fuels are to be fired the designer should attempt to provide for water washing of the air heater in the initial design. If proper consideration is given to the design and operation of tubular air heaters the result should be a relatively low cost heat recovery apparatus which is effective, economical and has excellent availability.

Cast Alloy Resistance to Flue-Gas Corrosion

J. H. Jackson, C. J. Slunder and **O. H. Harder** of the Battelle Memorial Institute and **J. T. Gow** of the Electric Steel Foundry Company presented a paper entitled "Resistance of Cast Fe-Cr-Ni Alloys to Corrosion in Oxidizing and Reducing Flue-Gas Atmospheres" in which they reported an investigation of the corrosion of iron-chromium-nickel castings by sulfur-bearing gases at 1800 to 2000 F. The sulfur was varied from 0 to 500 grains per 100 cu ft in both reducing and oxidizing flue gases. In general, corrosion in the higher sulfur-bearing atmospheres was much less severe when the flue gas was oxidizing then when reducing.

Engineers designing with cast Fe-Cr-Ni alloys should base their selections of these materials on data which reveal how the metal beneath the surface is affected by corrosion; they should not be influenced entirely by values of rates of surface scaling or metal loss alone. It has been found that in cast high alloys the subsurface attack may consist of decarburization, intergranular or interdendritic penetration of corrosion, or a massive infiltration of the corrosion product into the metal surface.

In the experimental investigation it was noted that the effect of increasing the temperature of the flue-gas atmosphere from 1800 to 2000 F is to make the corrosive attack more severe. With reducing flue-gas atmospheres containing 500 grains of sulfur per 100 cu ft at 2000 F, rates of attack were very high even for the 30 per cent chromium, nickel-free alloys. Although cyclic temperatures appeared detrimental, cycling of the atmosphere from reducing to oxidizing did not appear to increase rates of corrosion.

It was also found that additions of silicon of 1.5 to 2.5 per cent resulted in marked reduction of corrosion (most commercial cast alloys contain about 1.2 per cent silicon). Additions of aluminum of about 1 per cent were also of great value in reducing corrosion and additions of molybdenum and vanadium resulted in slightly increased rates of attack.

Residual Fuel Oil Ash Corrosion

Operating experience with gas turbines using Bunker C oil has revealed a basic corrosion problem traceable to slag-forming substances that are present in the residual oil and corrode metallic parts. Such corrosion is manifest by short and unsatisfactory life of turbine nozzles, buckets and combustion-chamber liners, and ash deposits appear in the gas path. No such corrosion has been apparent with turbines run on natural gas.

A report summarizing laboratory tests and operating experience was given by **B. O. Buckland, C. M. Gardiner** and **D. G. Sanders,** all of the General Electric Co.

Both sodium sulfate and vanadium pentoxide in the oil slag were found to be responsible for corrosion. It is observed that since all slags cease to be corrosive at sufficiently low temperatures, one way of avoiding such trouble might be to design a turbine to operate at sufficiently low temperature. But this would impose a substantial disadvantage in size and economy of the unit, since the fuel rate decreases about 6 per cent for every 100 deg F increase in temperature.

Tests and experience indicate that by proper adjustments of the constituents of the ash and the choice of a suitable alloy, satisfactory operating life of gas turbine parts could be obtained. However, at present no such gas turbine alloy is in sight, the use of which alone would result in a solution of the problem.

This being the case, the authors suggest the use of additives in the fuel oil that will raise the temperature at which chemical attack by the ash occurs. Test results were cited showing the effect of an additive (chromium oxide) on the corrosion rate. It was pointed out further that residual oils, modified at the point of use by means of slurries and by means of mixing water solutions of additives to the oil, are beginning to be used with gas turbines in New England, although this appears to be an interim phase of the problem. It is possible that eastern residual oil suppliers may before long be able to furnish oil that is suitably modified when delivered. In that case the product would also be in demand by electric utilities who have experienced corrosion difficulties when burning residual oils in their steam power plants. This is especially important with the ever-increasing use of steam temperatures of 1050 to 1100 F.

A second paper dealing with the use of residual fuel oils in gas turbines was presented by **Philip Draper,** of Shell Petroleum Co., Ltd. This dealt with some difficulties experienced in Europe through ash deposition.

The author explained that crude petroleum normally contains a small proportion of non-hydrocarbon constituents in which metallic radicals are combined. They are not distilled off with the lighter petroleum products and are therefore concentrated with the residual fuel oil. When the oil is burned these constituents leave an incombustible ash containing metals largely in the form of oxides or sulfates.

The major components of ash from fuel oils are sodium, vanadium and sulfur. The forms in which they appear after combustion depends on some factors not fully appreciated.

Various proposals have been offered for the removal of the ash-forming materials, including filtering, centrifuging and solvent extraction. Since much of the ash-forming material is in solution in the oil the first two are ruled out, and the third is too expensive. It was finally concluded that no method could be devised that is cheaper than distillation, which means that residual oils of the boiler type must be used just as they are produced and development work will have to be confined to the gas turbine to render it capable of digesting such fuels without undesirable after-effects. Much work has already been done on the combustion of distillate fuel oils in the case of jet engines.

Additives to Fuel Oil

A paper reporting on the application of additives to fuel oil to raise the fusing temperature of the ash and thereby change the character of the slag was presented in two sections. Part 1, by **J. B. McIlroy** and **E. J. Holler, Jr.,** both of Babcock & Wilcox, surveyed the general problem and described the laboratory phase of the investigation. Part 2, by **R. Lee,** assistant superintendent of power production with the Florida Power Corporation, reported on experience with both alumina and dolomite, as fuel oil additives, at the Inglis Station of that company. The unit upon which the trial was made is a 300,000-lb per hr, 900-psi, 950-F two-drum boiler.

The additives in powdered form were mixed with the heated fuel oil in quantity equal to that of the ash in the oil to form a slurry. Both dolomite and alumina were effective in replacing a hard adherent deposit by a powdery ash that could be easily removed by air lancing twice a week.

Dolomite was more effective in reducing the vanadium content of the ash, whereas the alumina caused a greater reduction in sulfur and raised the fusion temperature of the ash to a higher value. However, the dolomite, which is a natural mixture of calcium and magnesium carbonate, costs only about one-fifth that of alumina and was considered very satisfactory as contributing to lower maintenance cost, increased availability and higher efficiency of the unit. Furthermore, it tended to lower the dew point of the stack gases and thus reduced their corrosive character.

As a result of this experience, the Florida Power Corporation is now employing dolomite as a fuel oil additive at its Turner Station, as well as at Inglis.

Mercury Boiler Corrosion

The problem of reducing to a tolerable degree the corrosion of steel furnace in fogbank tubes in the mercury boiler of the Hartford Electric Light Company was investigated at the Battelle Memorial Institute and reported in a paper entitled "Corrosion of Mercury Boiler Tubes During Combustion of a Heavy Residual Oil" by **A. M. Hall, D. Douglass and J. H. Jackson.** Ash from combustion of heavy residual fuel oils was considered to be the primary corrosive agent, and protection of the furnace and boiler tubing by means of a suitable coating was investigated in bench-type pilot-plant and field tests. A metal sprayed coating consisting of approximately 74 per cent iron and 26 per cent chromium holds promise of being satisfactory. Although coatings of silica and magnesia showed promise among ceramic materials, further consideration was dropped, because they were judged to be too brittle to withstand the mechanical abuse inherent in the service.

Before applying the metallic coating, the tests showed that the boiler tubes should be cleaned by removing the heavy ash deposits and scale with a pneumatic hammer, followed by blasting with chilled-iron grit. A metal-spray gun could then be used to apply the metallic coating.

Laboratory results indicated that the coating was permeable by gaseous combustion products, and attempts were made to decrease permeability and improve bonding by heating the coating subsequent to deposition. However, this and other methods that were tried to

increase the protectiveness of the coating failed to effect an improvement sufficient to justify their use.

Fuel additives were also considered and the one found to have the most desirable property was a calcium soap derived from tall oil. This compound could be made cheaply and dissolved in kerosene in advance of its use as an additive. When added to the fuel oil in the ratio of three atoms of calcium in the tallate to one atom of vanadium in the fuel, it gave a strong indication of being effective in reducing tube corrosion. The corrosion rates of specimens in a pilot-plant run where calcium tallate was added to the fuel were of the order of 40 per cent of those for the corresponding specimens in the preceding run where no fuel additive was used. However, in appraising the effectiveness of the calcium tallate additive, account must be taken of the fact that a different, though comparable, fuel oil was used, and the test furnace operated somewhat more smoothly during the run where the additive was used.

Hot Lime Zeolite Conversion

G. H. Gowdy of the New England Gas and Electric System and **S. B. Applebaum** of the Cochrane Corporation presented a paper entitled "Conversion of a Two-Stage Hot Process Water Softener from Hot Lime-Soda Phosphate to Hot Lime Zeolite at Cambridge Electric Light Co." The Kendall Square Station of this company consists of two boilers operating at 1350 psig 900 F. and evaporating 200,000 lb of steam per hour each; it was initially started up in June of 1949. Because of the extraction of large quantities of steam at 200 psig for heating and process purposes, the makeup for this plant is unusually high, reaching as much as 30 per cent at times.

Initially a two-step hot lime-soda, hot phosphate plant was installed having a capacity of 16,000 lb per hr. However, by 1951 makeup demands exceeded 20,000 gal per hr and it was decided to convert the system to the use of hot lime zeolite, which doubled the capacity of the plant to a continuous rate of 32,000 gal per hr. In the conversion three additional anthracite filters were added, and above them were located three new hot zeolite units.

In operating the new plant which was placed in service early in 1952, it was found that some silica reduction took place through the hot zeolite unit. This reduction, which meets the limiting requirement of 0.5 ppm, is not an ion exchange reaction but is the result of adsorption phenomena. The authors believe it must be due to microscopic films of magnesium hydroxide on the finer zeolite granules which have a high adsorptive capacity due to their greater surface area. It is interesting to note that new zeolite freshly installed does not possess the silica removal property, but after operating for several weeks, it was reported, the film developed and the silica removal began. This film, however, does not interfere with the normal ion exchange.

Operating experience with this conversion discloses a number of noteworthy advantages:

(1) Alkalinity has been generally under 25 ppm so that CO_2 in the steam is generally under two to three ppm. This, in turn, is expected to decrease iron pickup in the condensate return.

(2) The elimination of phosphate in the external treatment of the water avoids phosphate precipitates and phosphate growth on filter anthracite granules.

(3) Total solids in the treated makeup have been reduced by about 16 per cent on the average, which reduces the requirements for boiler blowoff.

(4) Operating cost has been reduced from an average of $7.86 to $4.30 per million pounds of treated makeup.

(5) The control of the chemical treatment of this water has been considerably simplified by the elimination of soda ash, phosphate and caustic soda previously used at times in the past. This complication of chemical control was aggravated by the fluctuations in the Cambridge City water composition due to the admixture of different reservoir supplies in unexpected variable proportions.

Condensate Contamination

Results of studies on the contamination of condensate by heat-exchanger tube alloys at two power stations of the Virginia Electric & Power Co., namely, Bremo and Chesterfield, were reported in a paper by **J. D. Ristroph,** chief chemist of that company, and **E. B. Powell,** consulting engineer of Stone & Webster Engineering Corp. These studies, which involved twelve alloys, aimed at evaluating the influence of condensate temperature, dissolved gas content, flow velocity, and cumulative service time upon the degree of metallic contamination.

Under conditions of nominal feedwater and boiler water treatment, and of dissolved gas content usual for the drips from the stage heaters on the tests, with a 245–425 F temperature range, and within the time limits of the tests, Monel, 70–30 copper-nickel, and arsenical Admiralty Metal were found to be the heat-exchanger alloys of nonferrous or copper-bearing type showing the least tendency to contribute highly to such contamination. Also, type 316 stainless steel offered iron contamination at a rate not far from that of copper by the nonferrous alloys.

Increased condensate temperature was found to increase the contamination with all the alloys tested.

For several of the alloys higher dissolved gas concentration caused much greater contamination on some of the tests.

Treatment of feedwater with cyclohexylamine effected a marked decrease in the rates of contamination imparted by all the nonferrous alloys tested and prevented entirely iron contamination from the type 316 stainless steel. The response of the nickel-bearing nonferrous alloys to the cyclohexylamine treatment was less marked than that of the other nonferrous alloys. This was sufficiently so that the copper-nickel alloys were displaced by aluminum-bronze, aluminum-brass, phosphorized-copper and arsenical Admiralty Metal at the most favorable end of the scale.

Finally, the rate of contamination from contact with any of the ferrous or nonferrous alloys is strongly influenced by the nature and extent of prior nonmetallic contamination of the condensate.

Steam Piping Shock Tests

W. C. Stewart and **W. G. Schreitz** of the United States Naval Engineering Experiment Station, Annapolis,

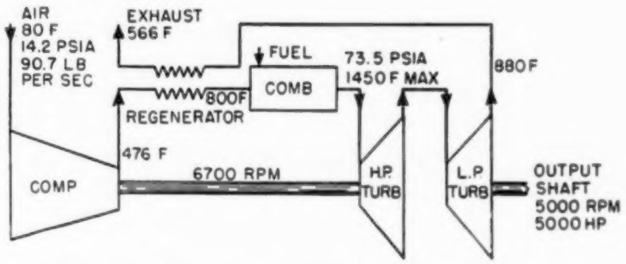
Md., presented a paper entitled "Thermal Shock and Other Comparison Tests of Austenitic and Ferritic Steels for Main Steam Piping." The results are summarized for thermal shock specimens and mock-ups of ferritic and austenitic steels, and complete test data are reported for a laboratory test program which was undertaken to supplement the full-scale tests. Thermal shock tests of six-inch pipe and valve assemblies in both 18–8 Cb and $2^1/_4$ Cr-1 Mo materials are described. Specimens were of two weights, schedules 80 and 160. The 160-schedule thermal shock specimens each contained a section of dissimilar pipe which introduced transition and composite welded joints. The shock treatment was designed to simulate the quenching action that might result from the carryover of boiler water into a pipe line carrying steam at 1050 deg F temperature. The steam pressure for the 80-schedule specimens was 900 psi, and for the 160-schedule specimens, 2000 psi. Each assembly was subjected to 100 shocks.

The effect of mechanical loading on full-scale members was investigated by testing mock-ups which were designed to simulate expansion bends. A mock-up corresponding to each of the four thermal shock specimens was tested. The mock-ups were formed by welding "s" bends to the connecting pipe and valve assemblies which were removed from the thermal shock specimens. Each mock-up was subjected to 4000 deflections so adjusted as to induce a range of equivalent stress predicated on changing from a safety factor of 5 to 4. The test was repeated for the 80-schedule ferritic mock-up and the 160-schedule austenitic mock-up but for a range of induced stress based on changing from a safety factor of 5 to 3. Following this, the two mock-ups were subjected to a range of reversed bending stress to failure. The condition of the welds as affected by the thermal shock treatment and the mock-up test is discussed.

Pipe Lines Gas Turbines

T. R. Rhea and **J. S. Quill** of the General Electric Company presented a paper entitled "Gas Turbines and Centrifugal Compressors for Natural Gas Pipelines" in which they described the general station arrangement, auxiliaries, main gas piping and valving of their company's 5000-hp, two-shaft gas turbines. These prime movers are direct connected to single-stage, adjustable-speed centrifugal compressors for moving natural gas in major gas trunk lines. They are essentially simple rotating machines and are complete, self-sustaining power plants in themselves, taking fuel directly from the pipe line and requiring little or no water and no outside electric power. Most of the functions and protective features of gas turbines are entirely automatic and therefore few operating personnel are required. At characteristic operating temperatures and speeds they are suitable for the continuous heavy duty operation required, and their reliability and maintenance is proving as good or better than steam turbines, when the latter are considered with their boilers and auxiliary equipment. In addition, natural gas is an ideal fuel for this type of prime mover.

The gas turbine is rated 5000 hp, 5000 rpm at 80 F ambient at an altitude of 1000 ft. Based on the lower heating value of the gas and the use of a regenerator or heat-exchanger, the machine has a thermal efficiency of 25 per cent. As shown in the accompanying schematic diagram, the shaft of the low-pressure load turbine is mechanically separate from the axial-flow compressor and its high-pressure driving turbine. This separation permits a wide range of speed at almost constant horsepower output. The machine has a characteristically flat output when load shaft speed is plotted against developed horsepower. A centrifugal compressor can be driven at 4750 rpm to absorb the 5000 hp available at



Schematic diagram of 5000-hp regenerative-cycle gas turbine

80 F, but in cold weather the unit can be speeded up to absorb the maximum available output of approximately 6400 hp at 40-F ambient temperature. This flexibility is desirable both to the compressor designer and to the engineer in applying these machines to pipe lines.

Use of Pellets for Slag Removal

Although it has long been common practice to remove slag rings from rotary coal-fired cement kilns by means of shot-gun discharge along the kiln axis, such a method, although occasionally reported, does not appear satisfactory for cleaning boiler heating surface. On the other hand, sandblasting of boiler heating surfaces during outage, after the large masses of slag have been removed by other means, has been employed extensively, although rather expensive. The subject has long been the object of many patent applications both here and abroad.

A paper by **W. F. Cantieri,** chief engineer of Diamond Power Specialty Corporation, described a system developed by his company, which employs compressed air for projecting small steel shot of B-B caliber as pellets. These are stored in a magazine chamber and fed by gravity around a fixed baffle and through an orifice plate into a feeder block. Here they are aligned for discharge through the barrel. The feed rate can be adjusted from 50 to 250 pellets per second, and a booster jet admits compressed air at a higher pressure than that used in the feeder. At least six feeders may be arranged in tandem to the same supply tank.

The device has been tested on a boiler at the Ridgeland Station of the Commonwealth Edison Company, Chicago, where pellets effectively removed slag at distances up to 30 ft from the muzzle. Further modification is under way to permit movement of the barrel in order to enable some sweeping across the surface of the tubes, and to permit aiming each gun individually while the boiler is in service.

Further development applies the pellet gun to a standard long retracting-type of deslagging blower.

Air Pollution Symposium

Dr. Robert A. Kehoe, director of the Kettering Laboratory, University of Cincinnati College of Medicine, discussed the health aspects of air pollution in detail, pointing out that knowledge gained through the Meuse Valley disaster in 1930 and the Donora smog of 1948 have enabled man to chart the means of avoiding similar disasters. He stated that facts gained from the study of industrial gases and fumes have enabled comparisons to be made regarding the average concentrations of air pollution over cities which indicate that, under ordinary conditions, gases and fumes do not occur in amounts sufficient to justify apprehension as to their effects upon health. Further study upon these problems is essential, especially to determine the effects of combinations of gases and fumes.

P. W. Zimmerman of the Boyce Thompson Institute for Plant Research, Inc., had as his topic "Air Pollution Indicated by Symptoms on Vegetation." He noted that corn is very sensitive to fluorides but relatively resistant to sulfur dioxide gas; and that squash is sensitive to sulfur dioxide gas but relatively resistant to hydrofluoric acid gas.

In general, when the symptoms found on wild species and garden plants are compared and matched up with experimentally induced symptoms, identification of specific impurities can usually be made.

Another paper entitled "Stack Diffusion" was presented by **E. Wendell Hewson** of M.I.T. Weather conditions govern the subsequent history of smoke once it leaves its stack. Wind direction tells where it will go. Concentration down wind is inversely proportional to wind speed but atmospheric turbulence is much more important in controlling concentrations. With low atmospheric turbulence the concentration at a given point may be a thousand-fold greater than with high turbulence. At stack levels the amount of this turbulence depends almost entirely on temperature with height. At such times as the temperature increases with height, turbulence is reduced and concentrations near stack-top level are high. Under certain circumstances where there is flexibility of emission or it can be arranged, the output of a contaminant may be varied in accordance with weather conditions; when diffusion is rapid the rate of emission is stepped up; when it is slow emission is reduced. The same principle may conveniently be used for intermittent plant operations which are not rigidly scheduled and which might lead to a pollution problem.

Education of the public or air pollution problems by every special means to bring about harmony between industry and surrounding communities was the theme of a discussion on "The Engineering and Management Viewpoint of Air Pollution" by **George F. Jenkins,** Carbide and Carbon Chemicals Company, South Charleston, W. Va. That management and its engineering talent is not only aware of these problems, but is honestly doing something about it, is not enough; the public must be made thoroughly acquainted with it. Mr. Jenkins then quoted from the statements of many top executives in American business which indicate that this is being done, but in too limited a manner for complete satisfaction.

In a paper entitled "Sampling and Measurement with Regard to Air Pollution," **Leslie Silverman** of the Harvard School of Public Health stated that there are two important fundamental aspects in sampling atmospheric pollutants. One phase may be regarded as source sampling and the other as area measurement and identification. In any problem in which atmospheric pollution is involved it is essential to determine the concentration and composition of the suspected contaminant or contaminants at their source. This means either sampling in a stack or collector discharge or inside the factory if the chief source of pollution appears as outward diffusion from a number of enclosed operations in a given building. Such sampling, if properly done, will of course determine the nature and composition of the contaminant, its particle size and physical characteristics, if particulate, and the highest possible concentration before dilution takes place.

The area sampling problem is next in sequence and having the information gained from source sampling it is possible to carry out a logical identification and measurement procedure for the suspected contaminants. In some situations, such as large scale smog problems where there are numerous and multiple sources of pollution, it is necessary to conduct a detailed area investigation since it is usually difficult to evaluate all sources.

Pulverized Coal for Locomotives

Although the Steam Locomotive Research Institute, Inc., no longer actively functions, some research begun in 1948 to determine the possibility of burning pulverized coal in a steam locomotive is reported in a paper entitled "The Combustion of Pulverized Coal in a Water-Cooled Radiant Tube" by **Ralph A. Sherman** and **Gerald E. Keinath** of the Battelle Memorial Institute and **R. Tom Sawyer,** who was chairman of the Technical Committee of the Institute.

This paper describes a series of trials of the combustion of pulverized coal in alloy-steel tubes from which the heat was absorbed by an outer, annularly spaced, water-cooled tube. Only one diameter of alloy tube, 5 in., in lengths of 10, 15, and 20 ft, was used for the trials. A high volatile coal, pulverized to a fineness of 90 per cent through a 200-mesh screen, was fired to this tube at rates of 40 to 160 lb per hr.

For the arrangement used, the fraction of the heat input in the coal that was absorbed by the water in the outer tube was only 20 to 40 per cent. Thus the particular arrangement used was not practical for a boiler. The interest in the tests lies in the fact that a coal whose ash softening and fluid temperatures were 2160 and 2220 F, respectively, was burned at extremely high rates of heat liberation without difficulty from slagging.

It appears possible that a tube of somewhat larger diameter would give a wall temperature high enough to have a satisfactorily low loss in unburned carbon and yet not so high as to result in difficulty from slag formation. The possibility of the application of this principle to the steam locomotive boiler prompted the research described, and a preliminary design of a 4–10–4 locomotive was prepared.

If your Management wants to

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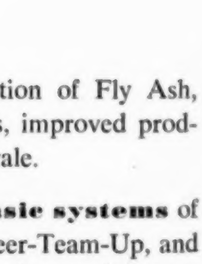

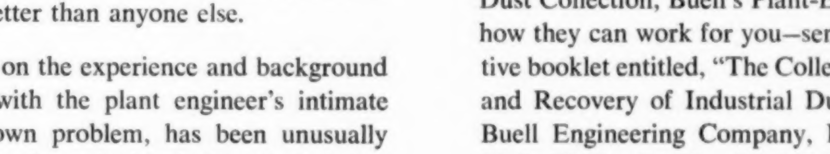

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ENGINEERED EFFICIENCY IN DUST COLLECTION

Instrumentation for Detection of Stack Emissions*

By GORDON R. HAHN
Division Engineer, Consolidated Edison Company of N. Y.

If reasonably efficient dust-collecting equipment has been provided, obnoxious stack emission from steam power plants is an indication of inefficiency in combustion. This, in itself has served as an incentive in the past for operators to try to maintain minimum discharge.

Recently, public sentiment has been directed against all types of plants for creating a smoke nuisance and causing air pollution. As the result of this, new smoke and pollution ordinances are being written and these and present laws are being more strictly enforced in many localities.

Because of this, it becomes wise policy to furnish the operator of equipment discharging through a stack with a more continuous knowledge of the emission created.

The prime consideration then becomes, "*What* information must the operator have available to properly control the stack discharge?"

The discharge may be either soft, oily, sooty particles of refuse or hard gritty ones either of which type is classed as a dirt nuisance. On the other hand, the discharge may not be a true nuisance; it may be a harmless condensed vapor such as water vapor, either discharged as such, or formed by condensation when reaching atmospheric temperatures.

Available Methods for Observing Stack Discharge

Four methods present themselves for keeping an operator informed of stack discharges which cannot be seen directly from the operating post. A person may be employed as "stack observer" who will keep the operator informed verbally by phone or public-address system. This wastes manpower, and, the opinion of another person has to be relied upon. However, it makes available the record of an independent observer. As an alternate, a mirror system may be arranged bringing a view of the stack emission to the control operator's location. This has limitations due to distances and maintenance of direct lines of vision clear of obstructions. Slight displacements of mirrors throw the image completely out of view, and mirrors must be constantly kept clean of dust, moisture, etc., to maintain a usable image.

Another method is the now familiar "smoke indicator or recorder," consisting of a light beam of constant intensity directed across the breeching to the stack or the stack itself with a light-sensitive cell on the opposite side. The output of this photoelectric cell is measured and either indicated or recorded in view of the operator. This method has the advantages of always being independent of human opinion and offering a choice of adding alarms. The maintenance problem offered is to keep the lens on the light source and the tube surface clean and also to keep the light beam directed on the cell, often a problem where expansions of breeching or stack occur. The fourth method is becoming increasingly popular. A television camera is trained on the stack and a viewing monitor in the control room gives the operator a picture of visible discharge so that he has knowledge of the direction and dispersion of the plume.

Of course, it is obvious that a disadvantage of this method is that it does not function other than daylight hours, and also is ineffective during heavy fogs or storms, when discharge may still be present. Also, it does not necessarily produce a true shade comparison of discharge and background, especially under varying lighting conditions. Furthermore the contrast of a television receiver is a manual variable control.

To inform the operator of wind velocity a wind direction indicator and a wind speed indicator may be placed in the central control room. The value of these data to the operator lies in the fact that depending on plant location, a discharge in some directions may not affect anyone, whereas in other directions the same discharge conditions may be harmful. The speed of the wind is helpful in judging the dispersion of the plume.

Armed with the proper combination of information described, and adequate process controls, the operator will be fully equipped to maintain stack discharges causing minimum nuisance.

Handling the Problem at Astoria

I should now like to describe how one organization, the Consolidated Edison Co., is spending money to control the

* Presented at Seventh National Instrument Conference, Cleveland, Ohio, Sept. 7–12, 1952.

stack discharge from the Astoria Electric Generating Station now under construction.

First, we incorporated in the design of the plant, the most efficient and most modern solid particle removal equipment for stack discharge. By installing a cyclone mechanical-type cinder catcher for removal of the larger, heavier particles and an electrostatic-type precipitator for removal of more minute, lighter fly ash, we have reduced the stack discharge of ash to a minimum.

Second, a special stack design had to be developed because of the station's location. Due to its proximity to La Guardia Airport, the Civil Aeronautics Authority limited the stack height to 300 ft. Also two gas holders, 270 ft. high, are located to the southeast of the electric plant and it was felt that with certain wind directions and speeds the stack discharge would blow over the gas holders and be drawn down by eddy action toward the ground near both a residential area and an approach zone of the airport.

These conditions were studied and the solution to this problem was given in a paper entitled "Studies of Stack Discharge Under Varying Conditions" presented by Ward F. Davidson, research director of Consolidated Edison Co., at the 44th Annual Convention of the Air Pollution and Smoke Prevention Association of America in Roanoke, Va., on May 8, 1951. He described the scale models which were made of the plant and all surrounding buildings and topography which were used in a wind tunnel research project at New York University.

These models showed that when the wind blows from the quarter that sends the plume over the gas holders, it is necessary to have the exit gas velocity four times the wind velocity in order to keep the bottom of the stack plume 100 ft. above the ground at this point. The meteorological conditions, based on La Guardia Airport data, led to the selection of 30 ft per second as the highest wind speed to meet the above requirement and hence the stack discharge velocity at this wind speed had to be maintained at 120 ft per second when the wind was from the northwest. As the station is bounded on three sides by water, winds from other quarters carry the discharge to locations where they are not objectionable.

In order to be able to maintain the required 120 ft per second stack velocity under unfavorable wind conditions even with partial load on the station and yet not waste fan power in wasteful stack gas velocity energy at other times, two stack construction features novel to power plants were decided on. One is an adjustable nozzle similar in cross-section to the inlet half of a venturi

nozzle which can be shut off by a butterfly damper of similar shape to reduce the orifice area and double the gas speed at any flow. The dimensions are so proportioned as to give at full load a stack discharge speed of 120 ft per second with damper closed and 60 ft per second with damper opened. At minimum loads these speeds normally become 30 to 60 ft per second. To produce 120 ft per second when required at minimum load the second novel feature provided a continuously adjustable damper as a bypass around the boiler to carry air from the forced draft fan outlet into the base of the stack. Control of these dampers has been located in the central control room under jurisdiction of the station control operator.

To inform him of the stack discharge conditions we have provided a television viewing monitor, as previously described, in about the most conspicuous location of the control panel. As an added check, a second viewing monitor is located in the office of the plant superintendent. Possibly of more than passing interest here is the fact that the air in the camera room is filtered to keep dust from collecting on the camera lens. The camera looks through a thermopane glass window equipped with a windshield wiper and defroster, both remotely controlled from the central control room. Also a light source is directed across the stack on a photoelectric cell whose output is transmitted to a recorder, with alarm, on the rear of the operating panel in the central control room. The reading is retransmitted to the control panel as an indication located adjacent to the TV monitor.

In this manner the stack emissions are remotely observed or supervised, as much of the time as possible. By means of sampling nozzles located atop one of the two gas holders, a continuous atmospheric sample is drawn to an atmospheric analyzer which, together with the television camera, is located in a room on the station side of the gas holder and built 20 ft above ground level. This air sample is passed through an analyzer containing a solution which absorbs sulfur dioxide. (In the case of combustion of coal or oil this is the obnoxious offender.) Then by electroconductivity of this solution a measurement of the SO_2 content in the atmosphere is determined. This reading is transmitted to a 24-hour chart recorder on the rear of the control panel in the central control room. A slide wire retransmitter furnishes the impulse for the reading to be indicated from 0 to 10 parts per million on a millivoltmeter type indicator which is located on the control panel directly below the stack television monitor.

Also the recorder is provided with contacts for an audible and visible alarm in the central control room. Thus the invisible discharge is monitored continuously.

Finally, means are provided for following or knowing the plume travel. Of course, this can be done visibly by the television camera. But for invisible discharge observation, a wind speed signal generator or magneto, and a wind direction transmitter consisting of a selsyn unit, are also located atop the gas holder tank. These operate indicating receivers located in the central control room on the control panel, just under the stack TV monitor and also adjacent to the atmospheric SO_2 content indicator.

We feel that with these features of instrumentation making stack discharge conditions available to the control operator who also has full knowledge of combustion conditions, as well as the controls for adjusting combustion conditions, along with controls for varying stack discharge speed, we have provided the most advanced and comprehensive system for overall supervision and control of stack discharge that has yet been devised.

Army Orders Railway-Mounted Gas Turbine Plant

The U. S. Army Corps of Engineers has awarded the Westinghouse Electric Corp. a contract in excess of a million dollars for the construction of a railway-mounted gas-turbine power plant. Intended to be used as an advance power generation unit in devastated areas, the plant will be contained in two non-self-propelled railway cars.

The generator car will contain a 5000-kw, 5700-rpm gas turbine designed to burn diesel oil; a geared speed-reducer to drive the generator at 3600 rpm for 60-cycle power, or at 3000 rpm for 50-cycle power; a 2400-volt a-c generator; the generator exciter; and a starting motor for the gas turbine.

The other car, known as the transformer-control car, will house a multi-voltage transformer, with output ranging from 2400 volts to 15,000 volts; high- and low-voltage switchgear; and two diesel generators for auxiliary power, one of which will supply the starting motor.

Demand for power in South Africa is increasing faster than capacity. The recent yearly report of the Electricity Supply Commission, with an installed capacity of 1,519,000 kw, states that it now has 1,043,000 kw under construction or on order for six existing and eight new power stations.

New Books

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

The Science of Flames and Furnaces

By M. W. Thring

Major emphasis of this British book is upon industrial furnaces. The author is head of the physics department of the British Iron and Steel Research Association and has also served on the staff of the British Coal Utilization Research Association. Although furnace design in the past has been more in the nature of a craftsman's art than a rational science, the engineer of today has available tools of fundamental research to aid his efforts.

The book tells how furnaces are built and how they function. Applications of the first and second laws of thermodynamics to furnace design are cited, and the rate and mechanism of heat release from fuels is considered. Sections are devoted to heat transfer and to the aerodynamics of hot systems. Two concluding chapters deal with the science of furnace construction and the application of scientific method to furnaces.

This 416-page book which sells for \$6.50 is primarily intended for the combustion research specialist rather than for the power plant designer.

Fuels and Combustion

By M. L. Smith and K. W. Stinson

This textbook has as its worthy objective the presentation of fundamental and factual information concerning solid, liquid and gaseous fuels and the problems associated with their combustion. It covers the general topics of fuel technology and the relationship of air, fuel, combustion products and the heat released. The book is basically intended for undergraduate engineers studying a fuels and combustion course which would follow work in fundamental thermodynamics and precede the applied courses in steam power, internal combustion engines and heating and ventilating. However, the practicing engineer will find much valuable data compiled in concise form and a number of useful bibliographies.

The opening chapter is devoted to all types of fuels. Then follows a very understandable treatment of stoichiometric analysis and thermochemical analysis. The process of combustion, including its mechanism and the manner of flame propagation, is next considered. Succeeding chapters take up physical properties of fuels, gas and oil burners, coal-burning equipment, and combustion in engines. An appendix in-

cludes a number of useful charts to aid in combustion calculations. At the end of each chapter there appears a list of stimulating questions and appropriate problems.

This 330-page book sells for $6.50.

Air Pollution

The Proceedings of the United States Technical Conference on Air Pollution sponsored by the Interdepartmental Committee on Air Pollution, of which Louis C. McCabe acted as chairman, comprise nearly 100 chapters and more than 850 pages of text. It is the purpose of the volume to bring together in one volume an authentic body of information on the nature and control of air pollution. Whether this has been fully accomplished is open to some question, for the treatment of some aspects of air pollution is curiously uneven. Judging from the relative space alloted to such areas as agriculture and health, it would superficially appear that problems of atmospheric contamination from power plants are relatively unimportant. And there appears to be little or no consideration devoted to contaminants emitted from internal combustion engines.

Perhaps the foregoing can be summarized best by quoting from one of the discussions which are included in the book:

"The major immediate need in the field of air pollution is organization of the present knowledge of the art. This does not mean the presentation of papers on one or another phase of the problem for those who are especially familiar with the field. It means the thorough, organized presentation of the existing knowledge in a handbook or manual form that will give answers to those who are not familiar with or who have not been able to follow the recent developments in air pollution abatement."

This is definitely a book for specialists of many diverse fields and perhaps is most suited as a reference for those doing basic research in particular aspects of air pollution. Among the specific topics covered, and for many of which bibliographies are appended, are the following: effects of air-borne fluorides on livestock, effect of sulfur dioxide on conifers, effects of fluorine on plants; relation of spectrum of particle size to air pollution, application of the electron microscope to air pollution, spectrographic analysis in air pollution; odors and their physiology and psychology, activated carbon as an aid to control atmospheric contamination, theory of sonic-type flocculators and collectors, design and use of incinerators, dust abatement from power plant stacks; skin effects of air pollutants, environmental cancer hazards caused by air

pollution, respiratory tract allergic effects from chemical pollution; atmospheric sampling by electrostatic precipitation, direct photograph of aerosol suspensions, a recording visibility meter; legal aspects of air pollution, problems of drafting air-pollution codes and laws, legal aspects and methods of control used in Great Britain; meteorological aspects of atmospheric pollution, stack meteorology as related to power plants, air pollution and fog properties, and the diffusion problem in hilly terrain.

The volume is priced at $12.50.

Gas Turbine Power

By G. M. Dusinberre

Widespread popular interest in jet propulsion has to some extent obscured the versatility of the gas turbine as a land and marine power plant. In his preface, Professor Dusinberre, who has had wide experience in naval gas turbine applications as well as in college teaching, appropriately points to the need for an elementary gas-turbine text written from the fundamental viewpoint of thermodynamics and fuel economy. He notes that those engineers best qualified to prepare such a work are largely engaged in research and development work, and makes his aim in writing the book to set forth the underlying principles in a manner understandable to the mechanical engineer.

The chapters devoted to the basic gas-turbine cycle and its variations are especially well written, incorporating both theoretical thermodynamic considerations and practical design problems. Separate chapters are assigned to turbines and compressors, in which deserved attention is given to dynamic relationships within the machines. Short chapters on combustion, heat transfer and part-load operation have specific applications to gas turbines. An interesting concluding chapter takes up further variations of the basic gas-turbine cycle, including water injection, supersonic compression, the complex, exhaust-heated cycle and air-compression refrigeration cycle.

This 250-page book which sells for $6.00 is another in a series of outstanding engineering texts by members of the mechanical engineering faculty of the Pennsylvania State College.

All-Purpose Diesels

By J. M. Robson

This is a practical work, based on British practice, for diesel engineers, manufacturers and users of all types of high-speed oil engines. It is concerned primarily with details of design and operation. Comprising 316 pages and selling for $10, it is very effectively illustrated by detail drawings and photos.

New Catalogs and Bulletins

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

Centrifugal Pump Selection

Allis-Chalmers Mfg. Co. has prepared a 12-page "Handy Guide to Selection of Centrifugal Pumps." It discusses axial and mixed-flow, close-coupled and double-suction pumps and includes a head-capacity table for Type S double-suction pumps. Various types of special purpose pumps are mentioned.

pH Recording and Control

The Brown-Cambridge system for automatic recording and control of pH is described in a four-page data sheet issued by the Brown Instruments Division of Minneapolis-Honeywell Regulator Co. It includes a discussion of measuring system components, adjustments for operation, as well as variations in recording and control systems for electric or pneumatic modes of control and single or multi-point recording.

Centrifugal Compressors

A well-illustrated 12-page bulletin covering functions, applications, ratings, features of design arrangements and control methods for single-stage centrifugal compressors has been published by American Blower Corp. Ways in which controls are designed to meet specific requirements are explained, and a chart shows discharge positions in 15 deg increments.

Metering Applications

A 20-page booklet describing metering applications for watthour meters has been made available by the General Electric Co. Designated GET-1905, the bulletin contains circuit wiring diagrams for the various metering applications. It also describes watthour-meter constants and register data, the determination of watts load, and the use of watthour meters with instrument transformers.

Industrial Turbine-Generators

This interesting 20-page booklet, prepared by Westinghouse Electric Corp., shows photographs of actual turbine-generator installations in such industries as textiles, manufacturing, metals, paper, lumber, petroleum, chemical process, and foods. It should prove of considerable reference value to those interested in industrial power plant design. Under each photo is a

detailed caption citing both steam and electrical characteristics of the installation. Applications include turbines of the following types: non-condensing, non-condensing single and double extraction, condensing single and double extraction, and condensing.

Flow Meters

Catalog 2300, prepared by the Brown Instruments Division of Minneapolis-Honeywell Regulator Co., presents information on a new line of evenly graduated flow meters for measurement, recording, indication and integration of fluid flows. Various types of equipment utilizing an induction bridge system for remote measurements and an electron flow recorder-indicator are shown in the 26-page catalog.

Indian Power Plant Nearing Completion

The giant Bokaro Thermal Power Plant on the Damodar River in India, a vital part of "India's TVA," is now nearing completion, according to The Kuljian Corp. of Philadelphia, engineers and constructors of this $35,000,000 project.

The first boiler which was erected in February has recently undergone testing and the first turbine-generator will be placed in commercial operation in December 1952. The completed station will have a capacity of 240,000 kw and consist of four 60,000-kw units each served by two 300,000-lb per hr boilers operating at 900 psig and 900 F total temperature. At present only three turbine-generators and six boilers are being installed.

The Bokaro power plant, the first high-pressure steam generating plant in the Far East, is part of a tremendous power program being undertaken in India with the help of funds secured through the World Bank, and with engineering and construction "know-how" supplied by the United States.

A group of seventeen engineers selected by the Government of India were trained in Philadelphia by the Kuljian Corp. and the equipment manufacturers to operate the new plant. They have now returned to India to be present during the final stages of construction and, under the supervision of Kuljian engineers, will undergo further training in the operation of the plant.

An earth-filled dam or barrage is being built in connection with this station to provide a reservoir for cooling water. A total of 477 miles of transmission lines with necessary substations and auxiliary equipment is also included in the project.

This plant, because of its location near one of the world's largest strip coal mines, will generate power at a phenomenally low cost.

Battelle in Europe

Battelle Memorial Institute, Columbus, Ohio, well known over the past 23 years for its widespread research in many branches of engineering, has lately extended its activities to encompass European research. Its new research center at Frankfurt, Germany, is scheduled for completion late in the spring of 1953; and, according to a recent announcement, another center is to be established at Geneva, Switzerland. In fact, at the latter place an engineering economics group is already working on industrial surveys and laboratory facilities are being prepared on a 16-acre tract. At Frankfurt the center will engage in chemical, metallurgical and selected engineering projects. Still other centers in western Europe are contemplated, and funds have been allotted for some twenty fellowships in German and Swiss universities.

In the United States the Institute at present has a staff of more than 1900 scientists, engineers and technologists and during the current year will have conducted an estimated twelve million dollars worth of research.

Battelle is privately endowed and will provide initial capital for European research, but later European and American industries with European interests will assume much of the expense.